School of Earth and Environment
INSTITUTE FOR CLIMATE & ATMOSPHERIC SCIENCE

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Severe weather over East Africa

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GCRF African SWIFT
Science for Weather Information and Forecasting Techniques

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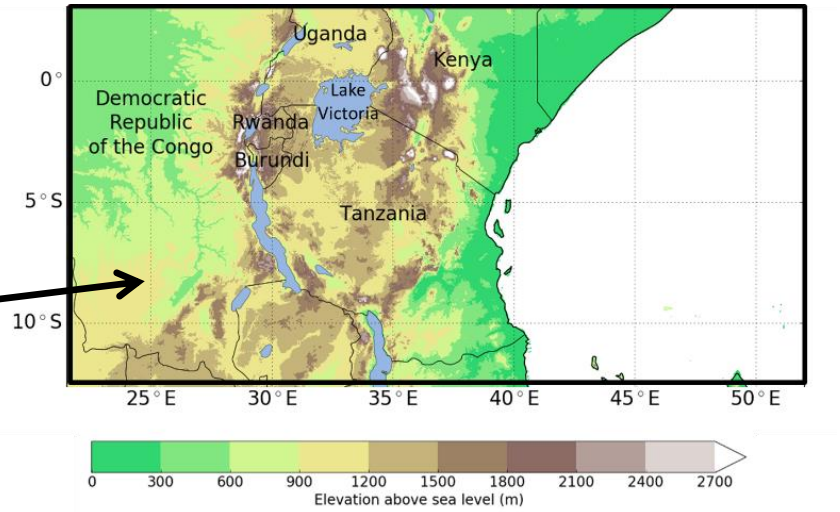
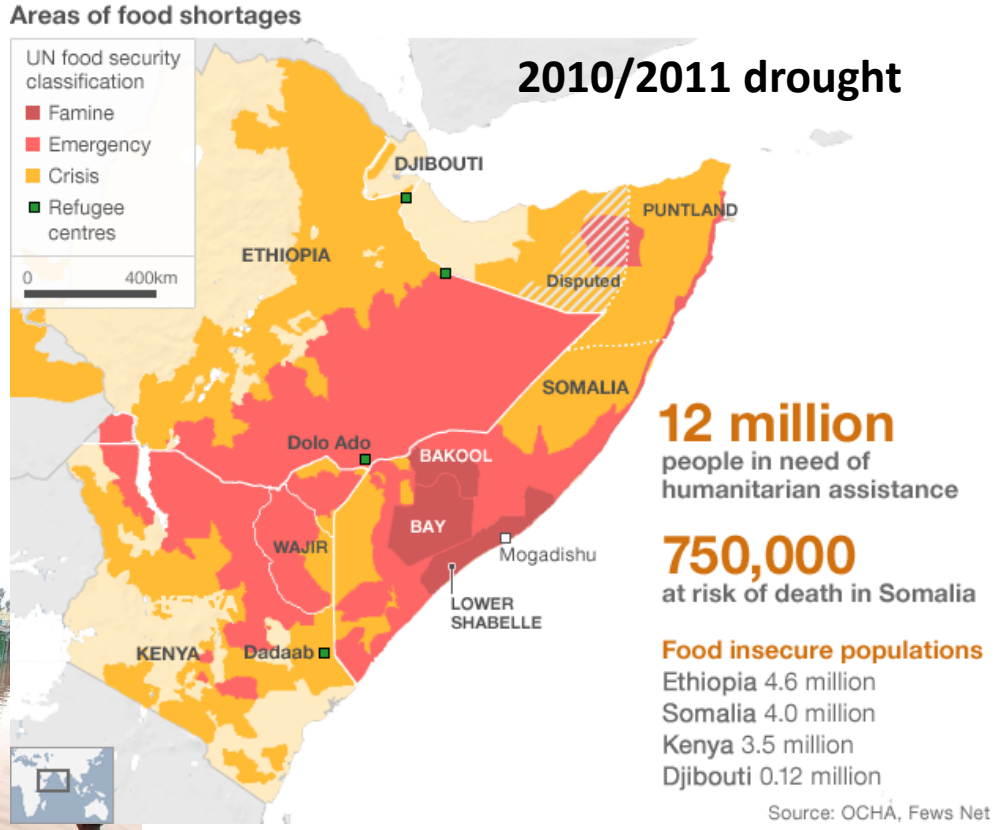
[1]University of Leeds, [2]Met Office, [3]Uganda National Met Authority, [4]University of Melbourne

Met Office

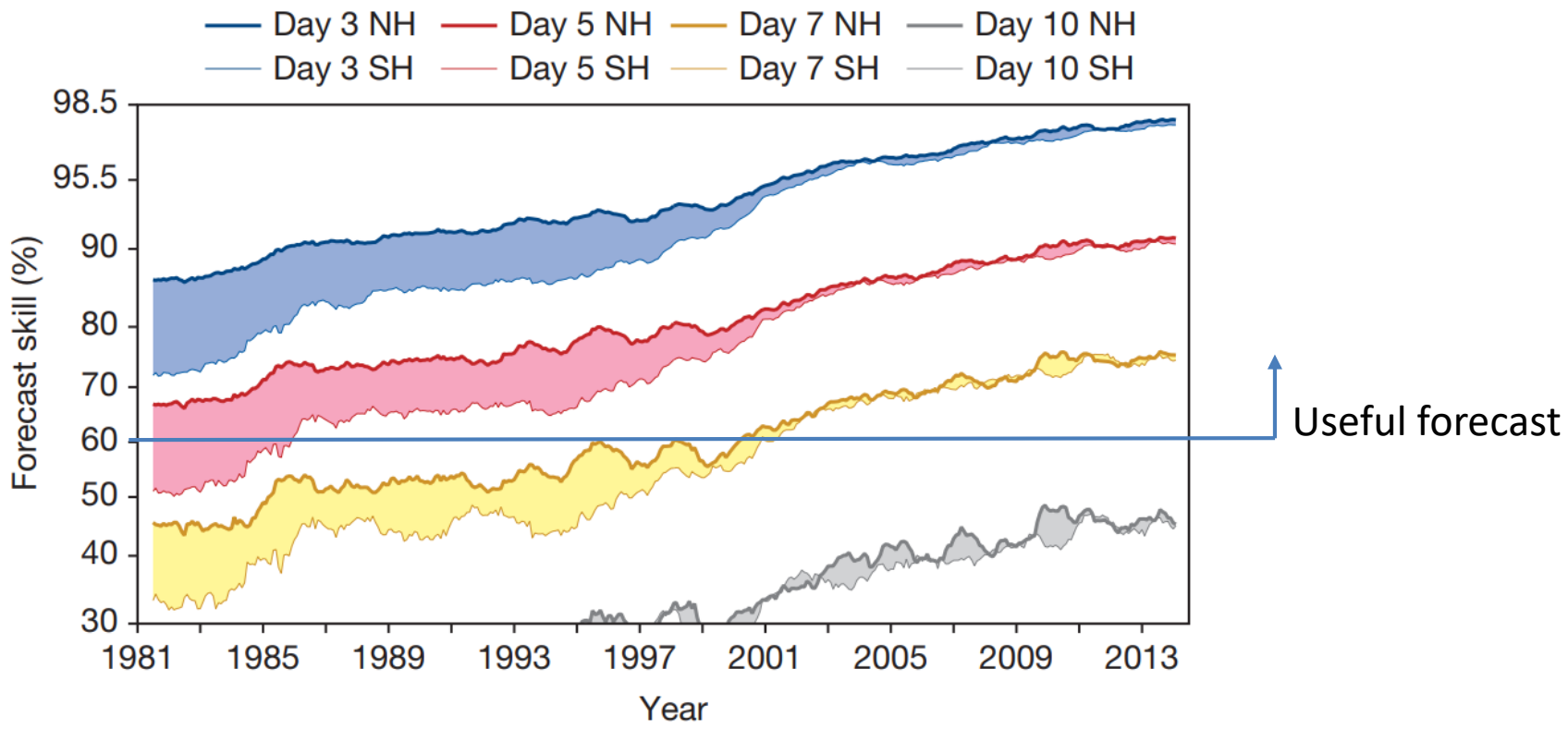
East Africa





- Hotspot for individual severe weather events
- Vulnerable to seasonal and decadal rainfall variability

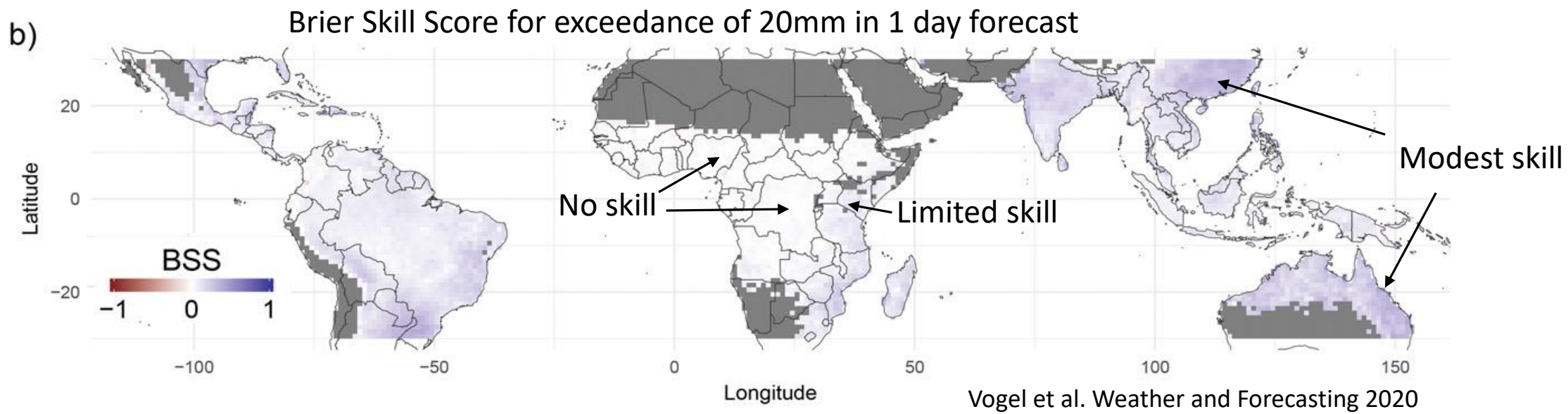
Extra-tropical weather forecast skill



- A 7 day forecast today is as good as a 3 or 4 day forecast in 1980
- Forecast skill has increased by a day per decade

Bauer et al. 2015

Global NWP forecasts of rainfall



Vogel et al. Weather and Forecasting 2020

- Almost no skill relative to climatology over most of sub-Saharan Africa
- Slightly better over East Africa
- Lack of routine observations, type of convective systems

Global NWP forecasts of rainfall

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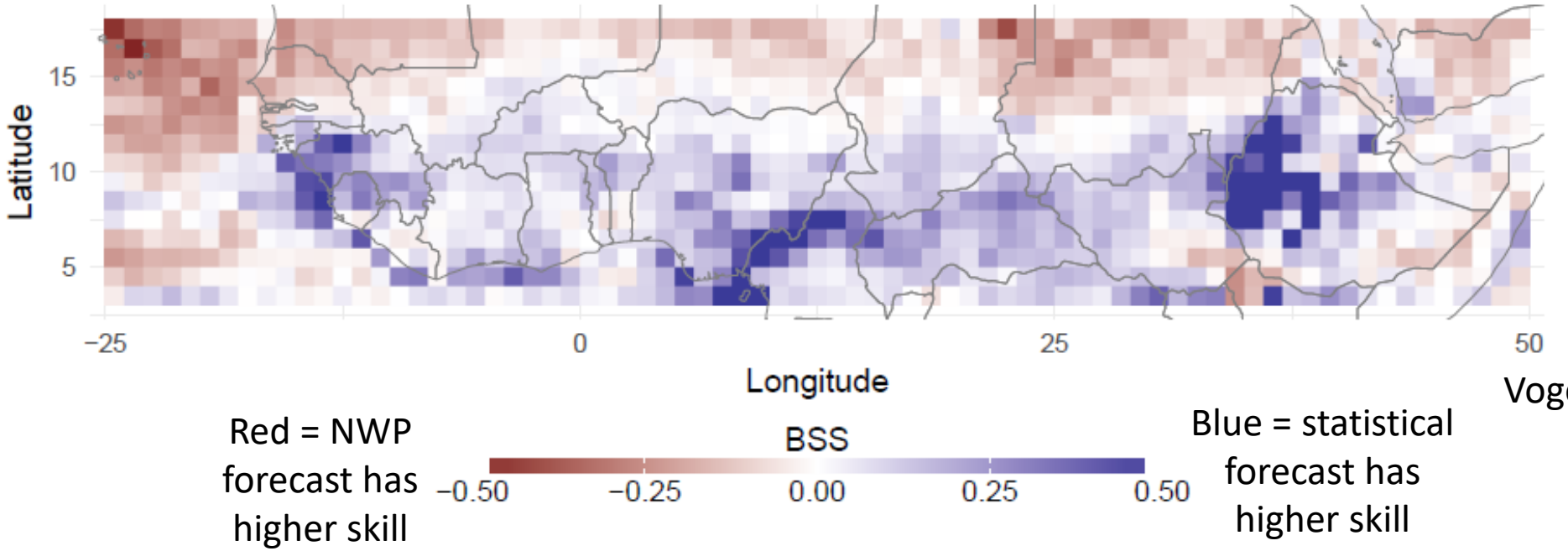

Vogel et al. GRL 2020

- In sub-Saharan West Africa, 1-day statistical forecasts outperform global NWP
- Rainfall is driven by convection within African Easterly Waves, which models struggle to represent
- Further north in dry outer tropics, NWP performs better

Sparsity of routine observations

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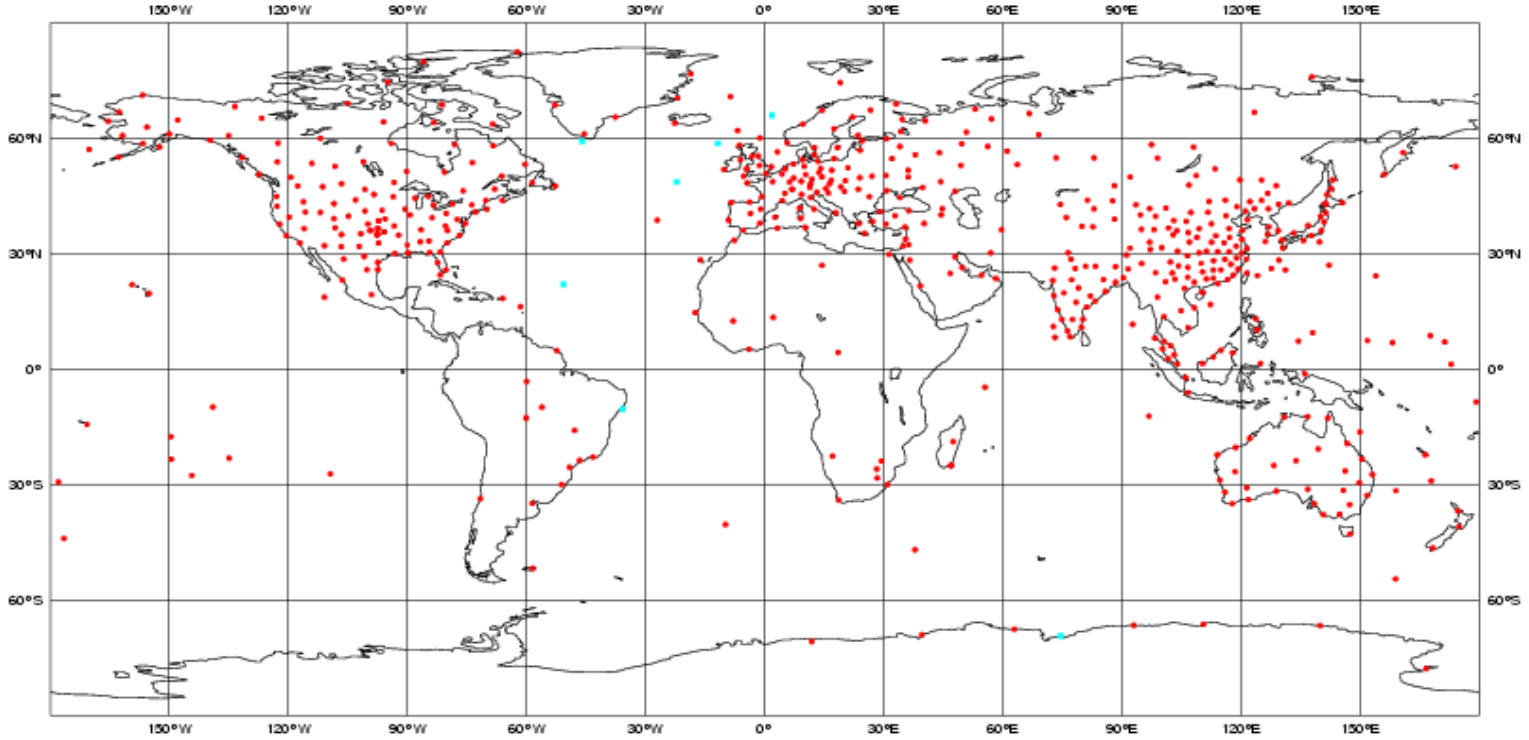
Global radiosonde network



- Africa has some of sparest in-situ observations in the world
- Reliance on satellite products in Africa – retrieved products = errors
- Lack of detailed observations (e.g. radar) for process studies and model evaluation

Convective-scale forecasting

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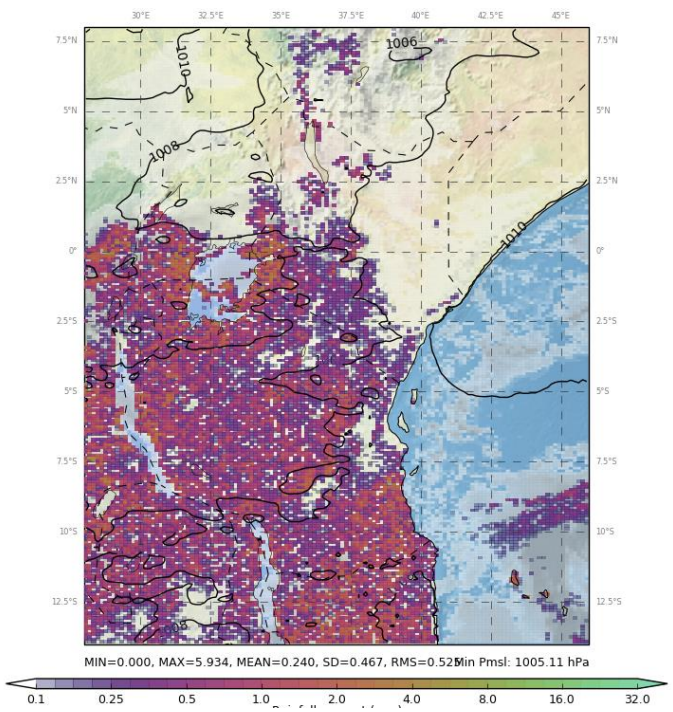
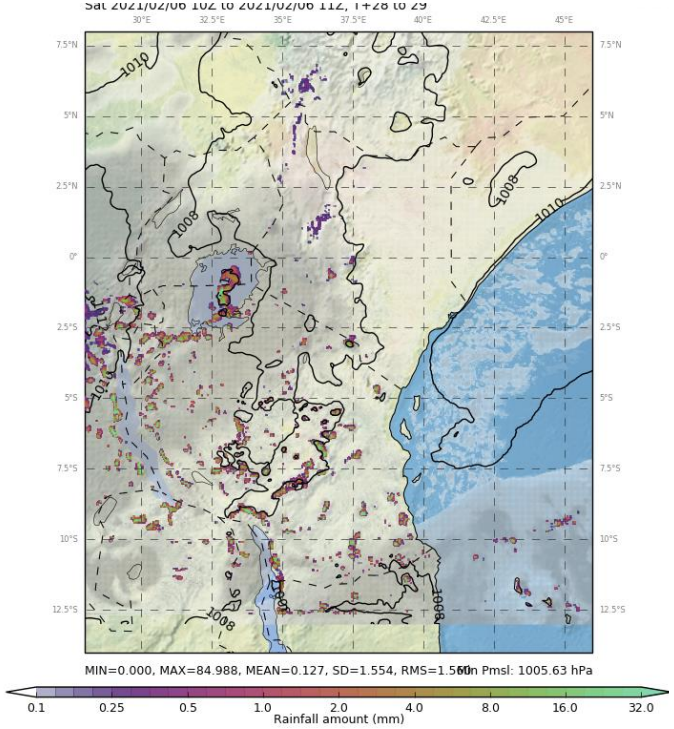
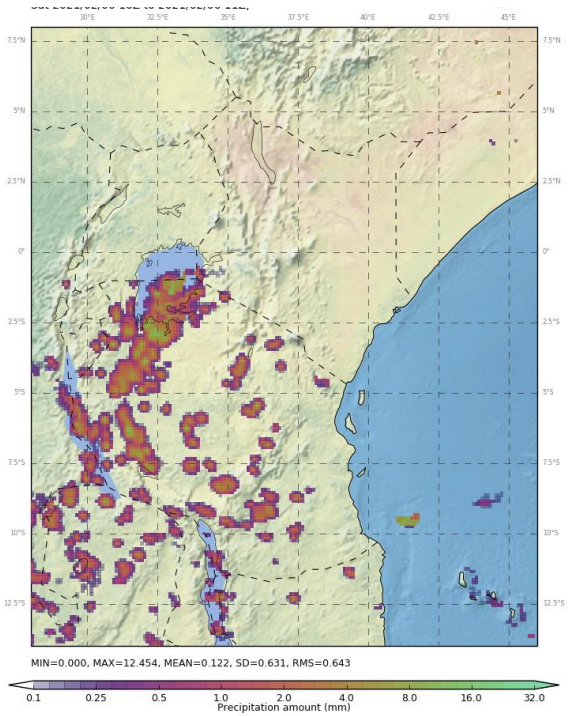
Global model



Convective-scale model



GPM observations

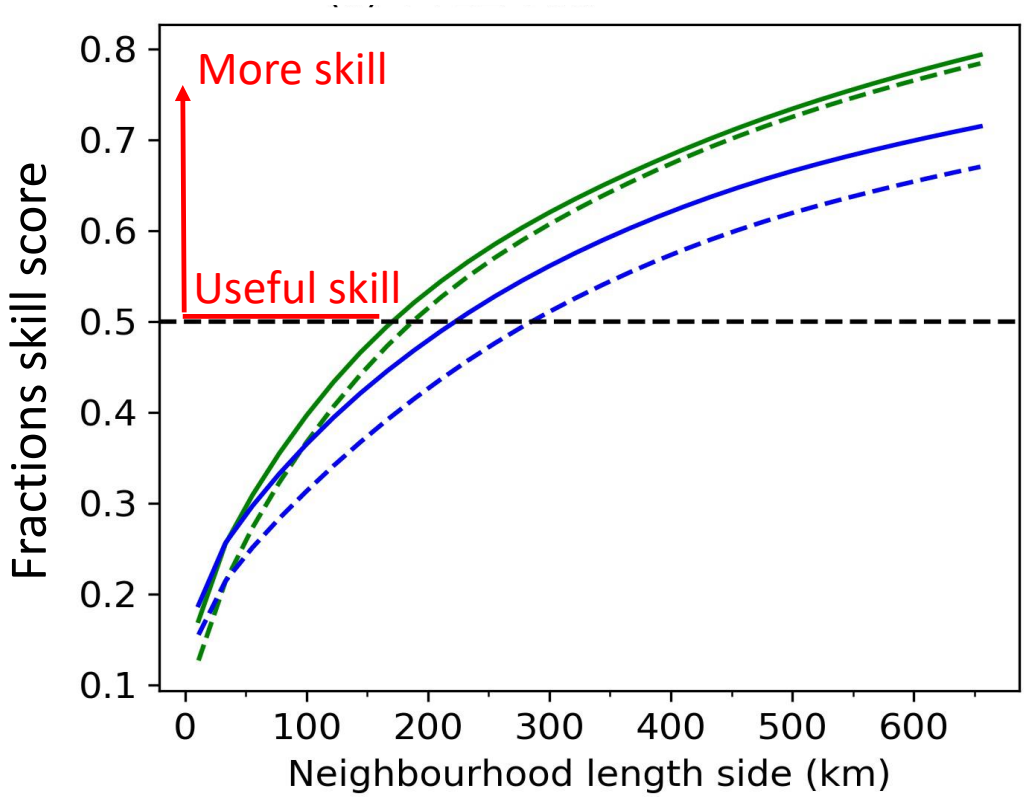


Met Office model forecasts 6th Feb 2021

- Higher-resolution allows convective processes to develop independently without the need for convection parameterisation
- Big improvement in the way storms ‘look’ in forecasts

Met Office

Convective-scale forecasts over East Africa

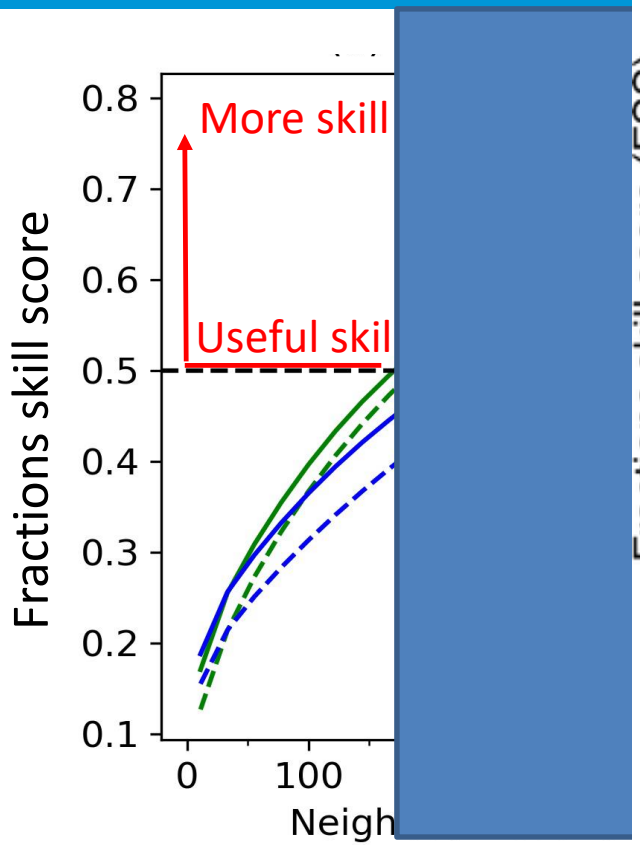


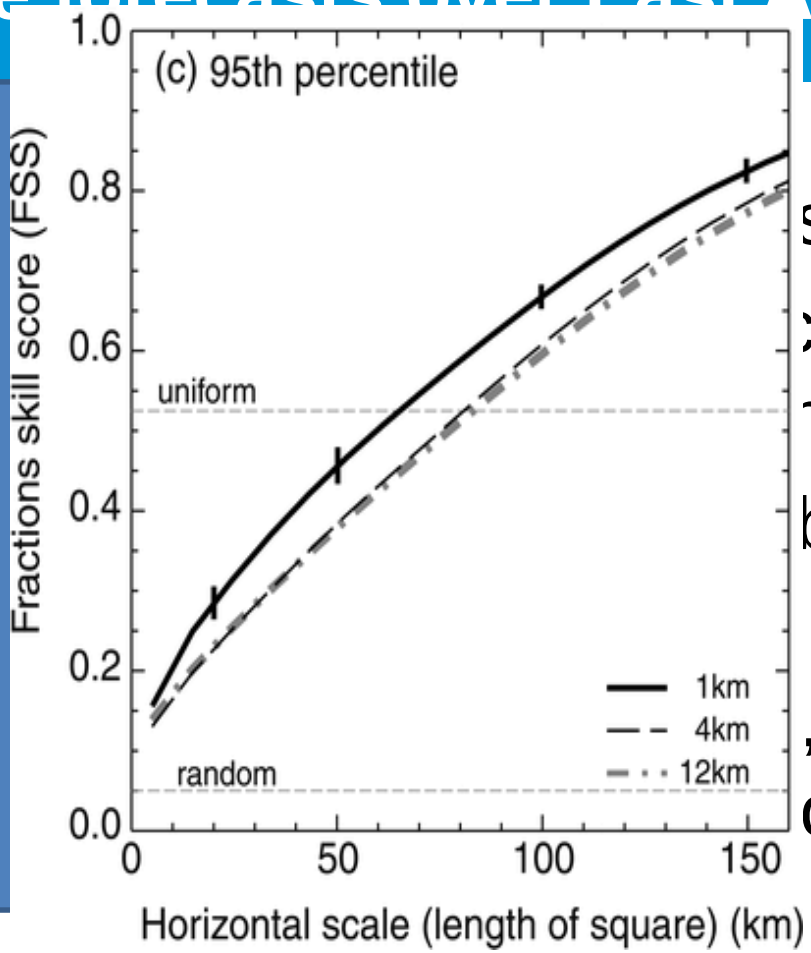
- Useful skill > 150km scales
- Convective-scale ensembles hardly worth the extra computational effort
- Ensembles do not provide enough spread
- Overall, skill much lower than in the extra-tropics

Global deterministic (MetUM)
Global ensemble (MOGREPS-G)
Convective-scale deterministic (Tropical Africa model)
Convective-scale ensemble

Woodhams et al. 2018; Cafaro et al. 2020

Convective-scale forecasts over East Africa





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Global deterministic
Global ensemble
Convective-scale deterministic
Convective-scale ensemble

Woodhams et al. 2018; Cafaro et al. 2020

Roberts and Lean (2008)

What next?

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1. Wait for more computing power to run higher resolution models, with more ensembles and add more processes
    - Could add more complexity and noise with limited improvement in skill
    - In wake of convective-scale revolution, smaller gains over longer periods of time
2. Improve routine observation network
    - Costly and challenging
    - Better observations only improve forecasts for the first 12-24 hours [e.g. van der Linden et al. 2020]
3. Improve model physics
    - Study rainfall and storm processes in more detail
    - Would lead to better parameterisations (but requires detailed observations)
4. Post-process existing model forecasts
    - Need to better understand model biases and atmospheric processes
    - Use new techniques like machine learning and artificial intelligence

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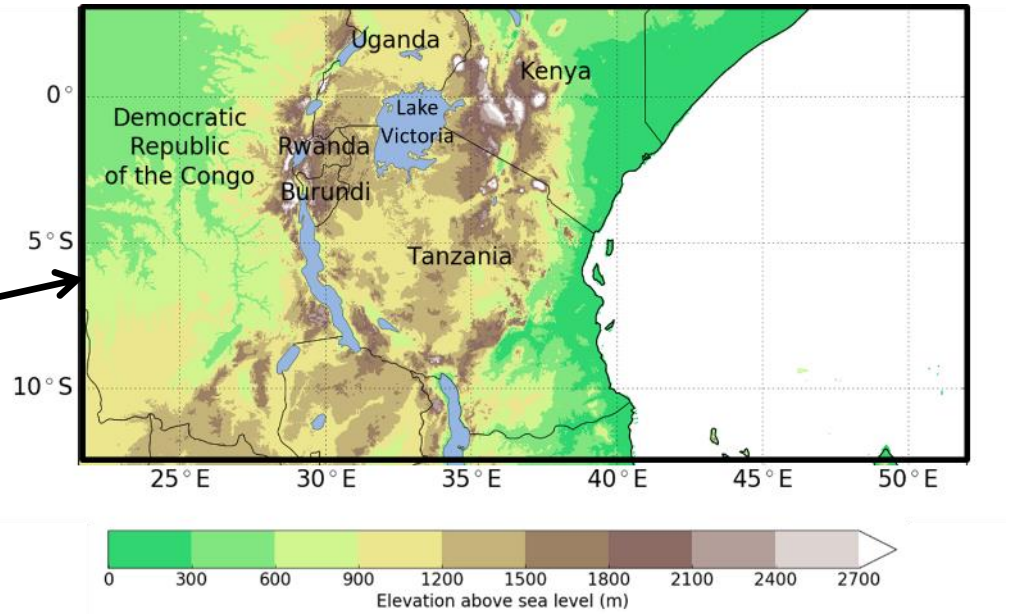
Lake Victoria



- Lake Victoria is a hotspot for severe convective storms - occur on average 175 days per year
- Storm warning service via text message
- Weather forecasts are no skilful enough – storms appear quickly and are unpredictable
- 200,000 fishermen use the lake
- 3000-5000 deaths each year
- Flooding

Lake Victoria

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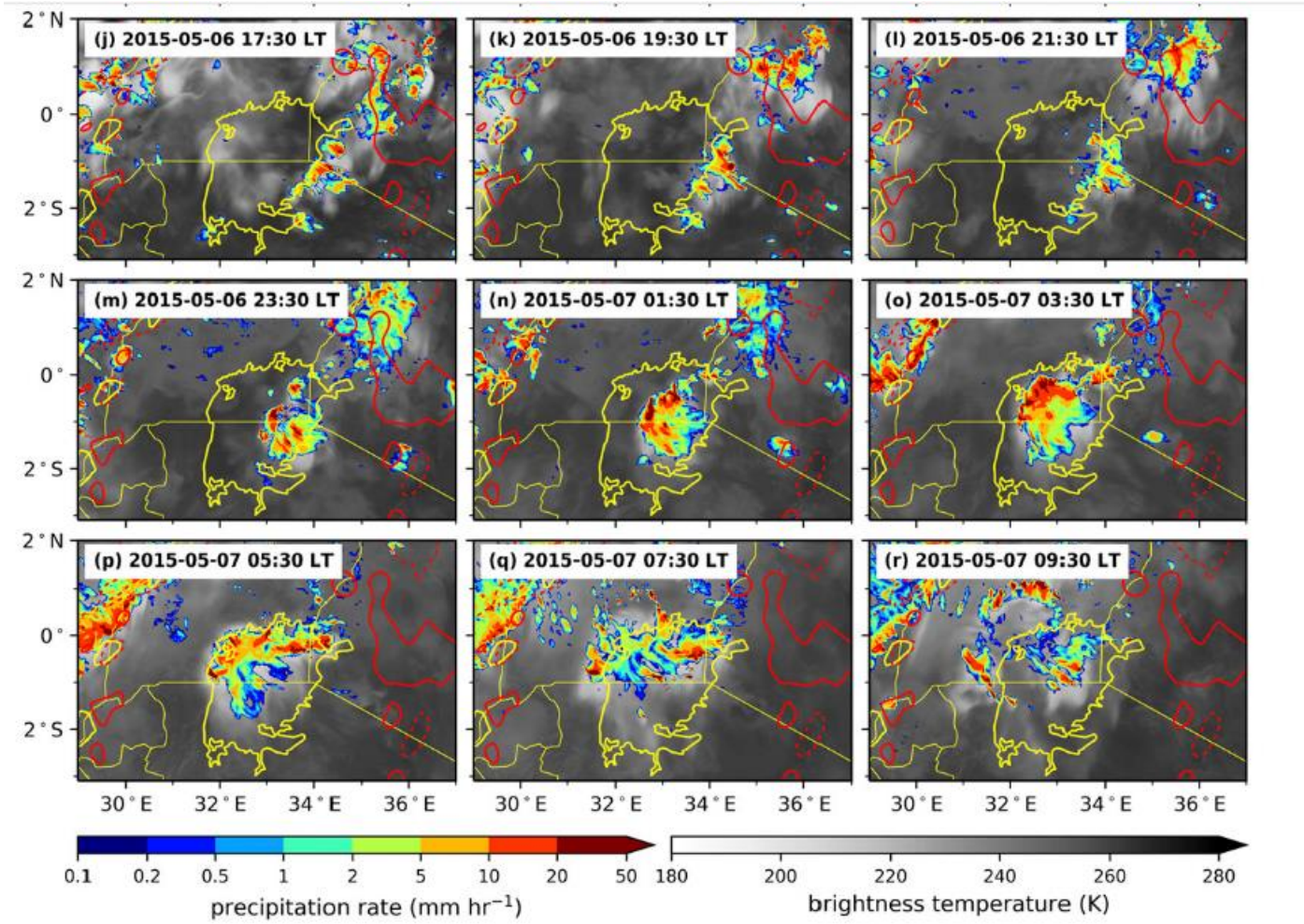
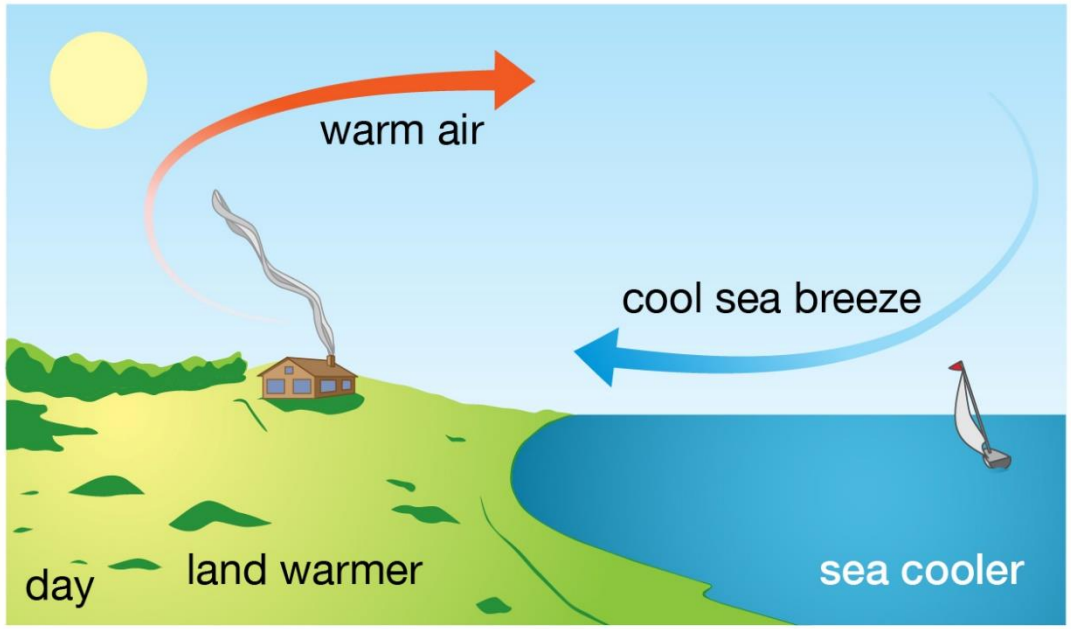
Storm over Lake Victoria 6-7th May 2015

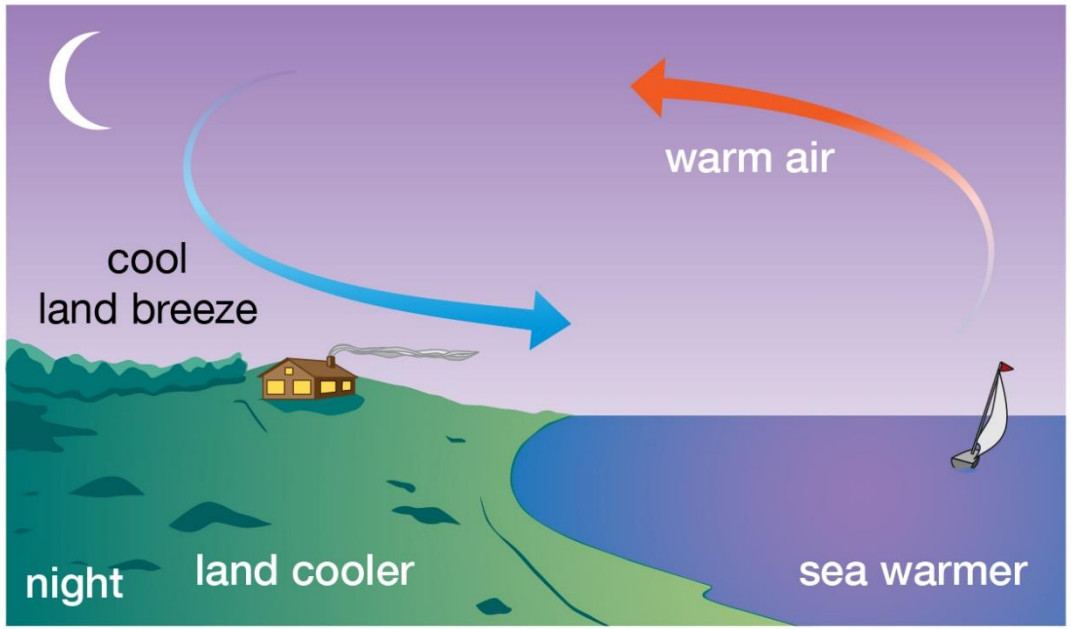


- Past studies have focused on the mean diurnal cycle of storms
- Storms do not occur every day, even in the wet season, so the mean diurnal cycle is not a good predictor of storms
- A basic, process-based understanding of what causes individual storms to initiate, develop and propagate is lacking

Woodhams et al. (2019)

Sea breeze circulation





- Lake-land breeze structures are likely important for triggering storms over Lake Victoria

Lake Victoria

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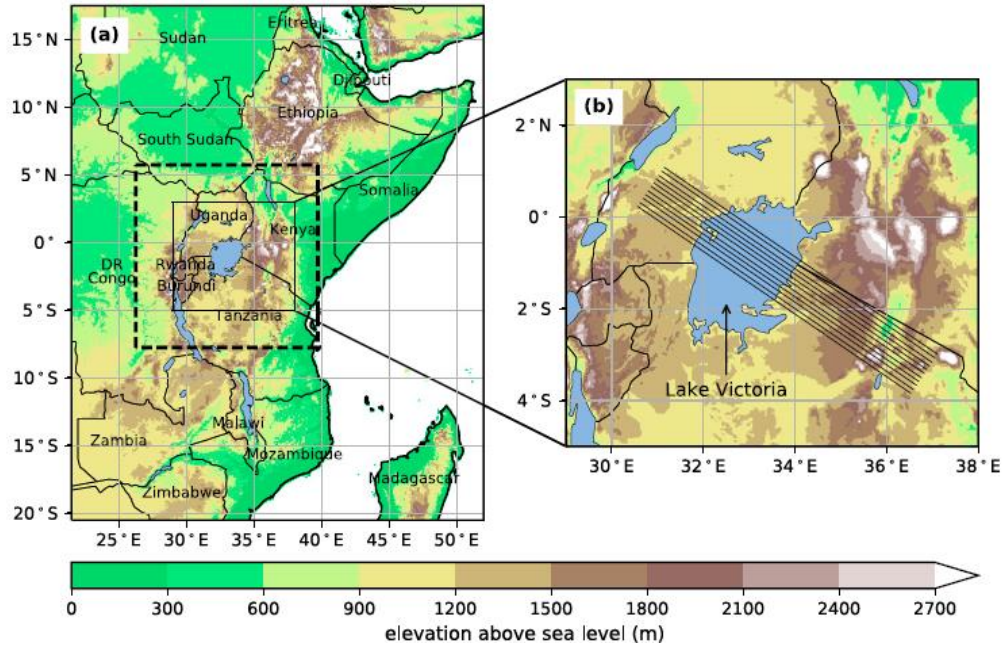
1.5km MetUM convective-scale simulations:

1. No storm – to understand baseline lake-land breeze
2. Storm in wet season
3. Storm in dry season



Case	Start Date	Run length	Period of interest	Description
Dry period	0000 UTC 9th July 2015	72h	1200 LT 10th to 1200 LT 11th July 2015	Three-day period with no significant rain over Lake Victoria
Long rains storm	1800 UTC 5th May 2015	72h	1200 LT 6th to 1200 LT 7th May 2015	Storm forms over land on the evening of the 6th and propagates onto Lake Victoria overnight
Dry season storm	1800 UTC 27th July 2016	72h	1800 LT 28th to 1200 LT 29th July 2016	Storm forms over Lake Victoria during the early morning of the 29th

Woodhams et al. (2019)

No storm case

No storm case

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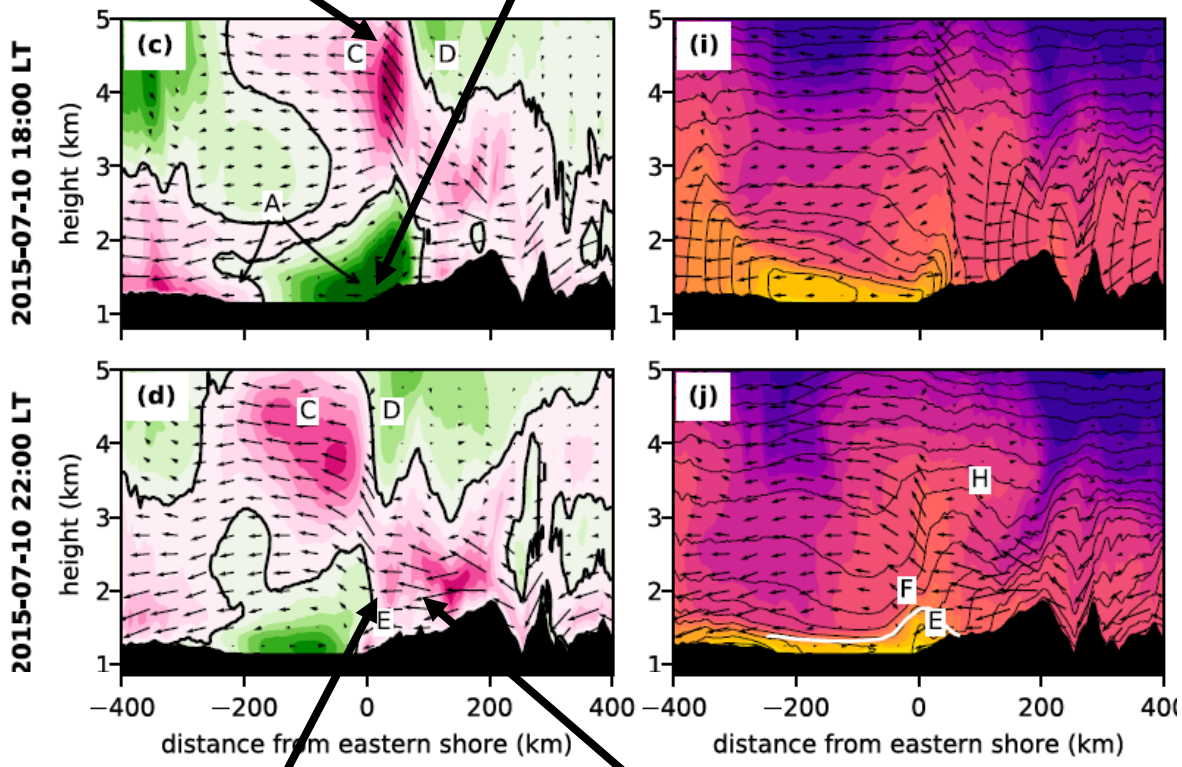
Return flow above

Strong onshore flow in the afternoon

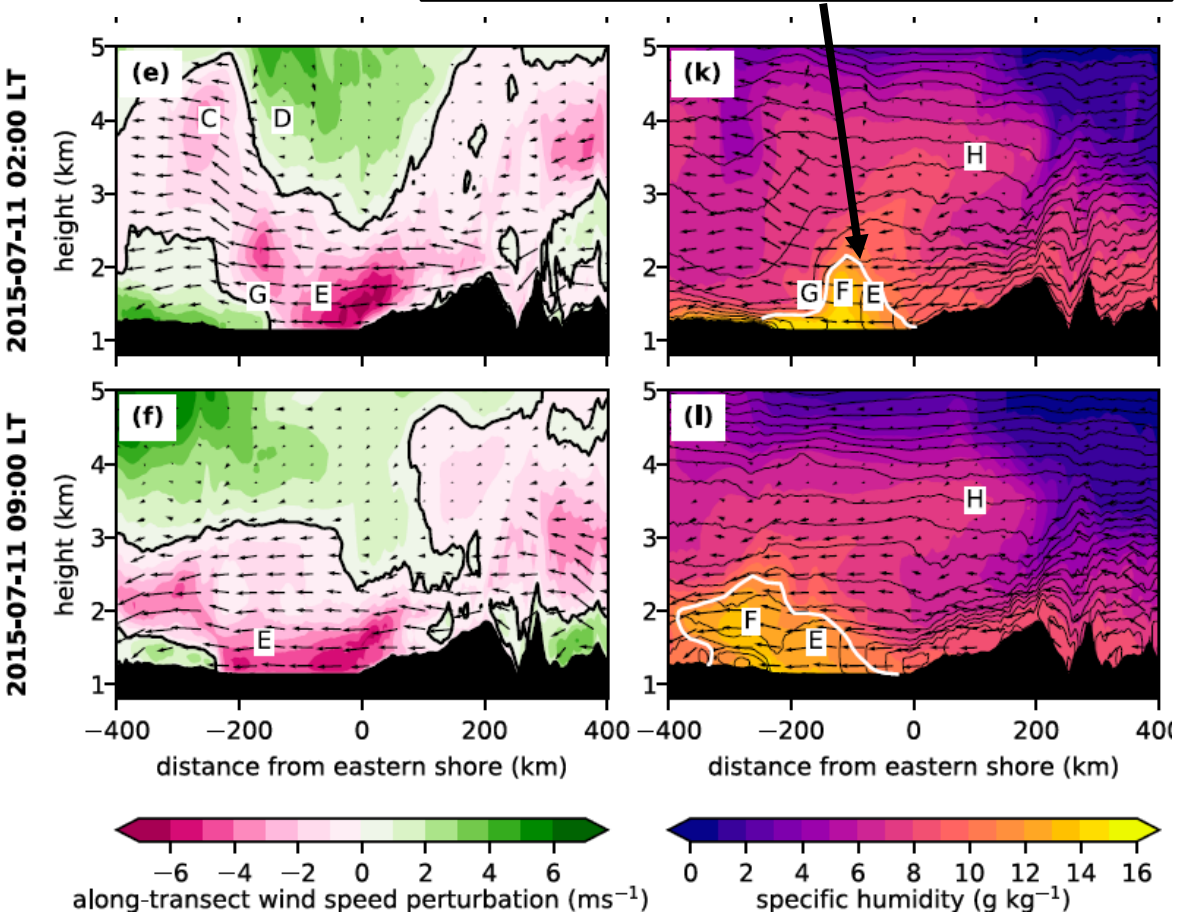


Convergence zone over the lake

Offshore flow, strengthened by prevailing winds and downslope mountain flow

Woodhams et al. (2019)

Bulge of moisture propagates with leading edge of land-breeze front



No storm as limited moisture availability

No storm case

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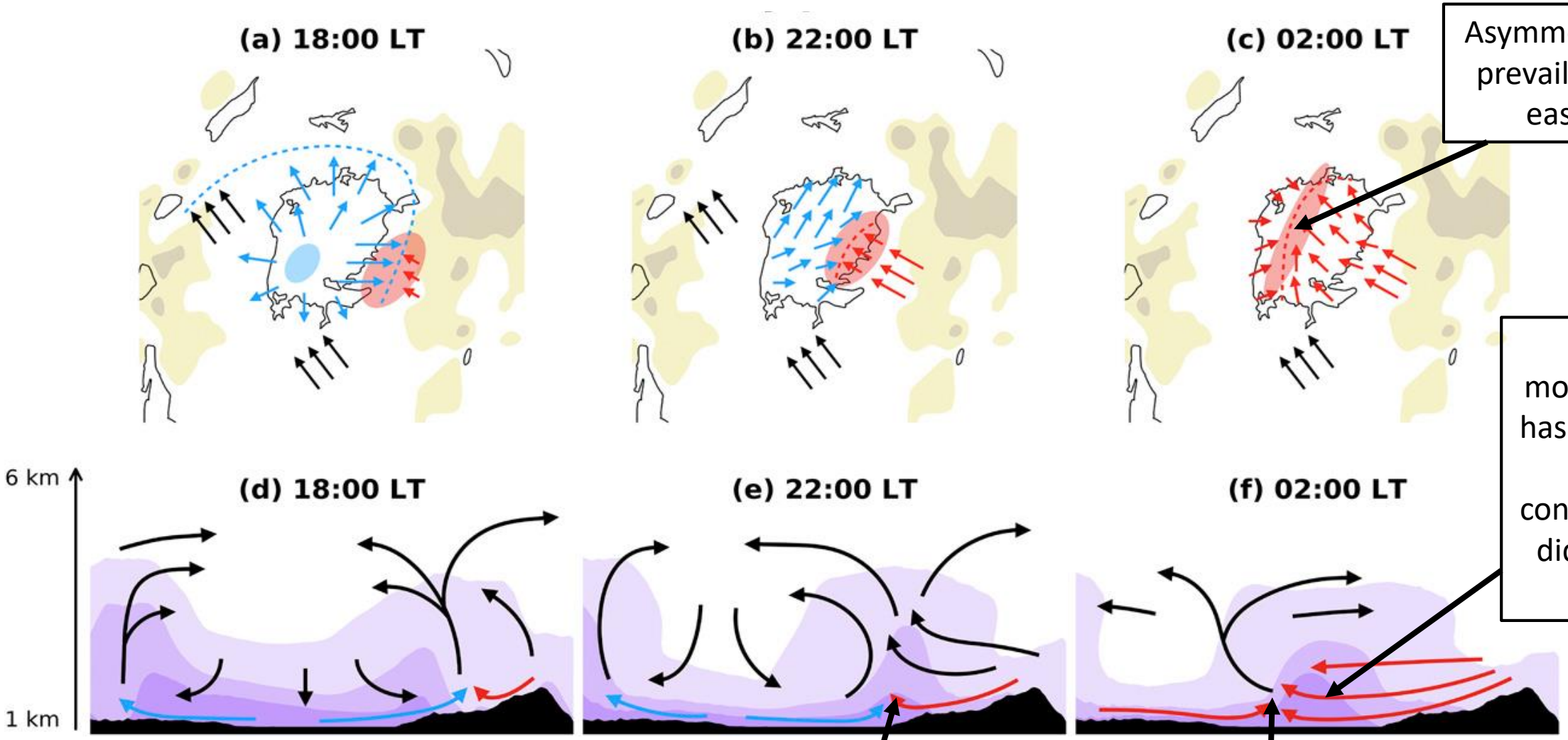


Asymmetry due to prevailing south-easterlies

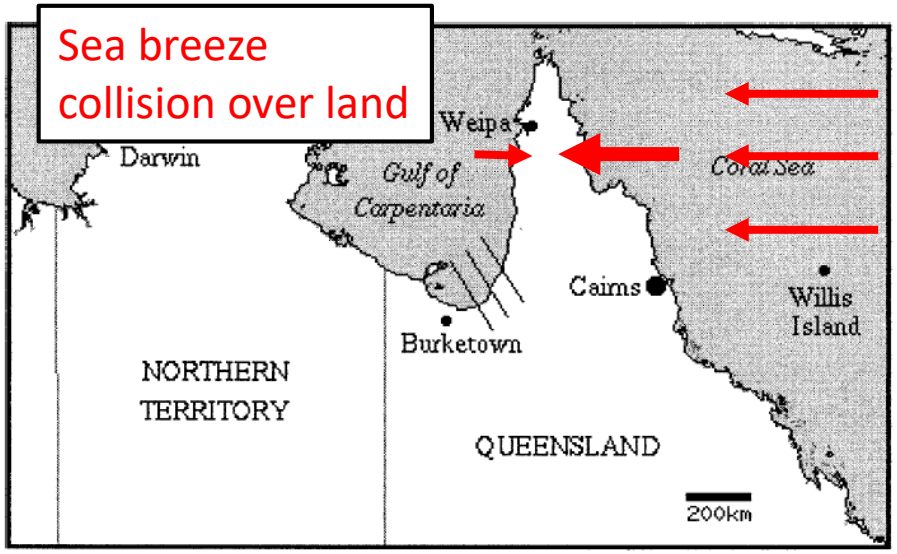
Elevated moisture bulge has potential to initiate convection (but didn't on this day)

Gusty winds at the head of land breeze density current could pose a hazard to fishermen even on dry days

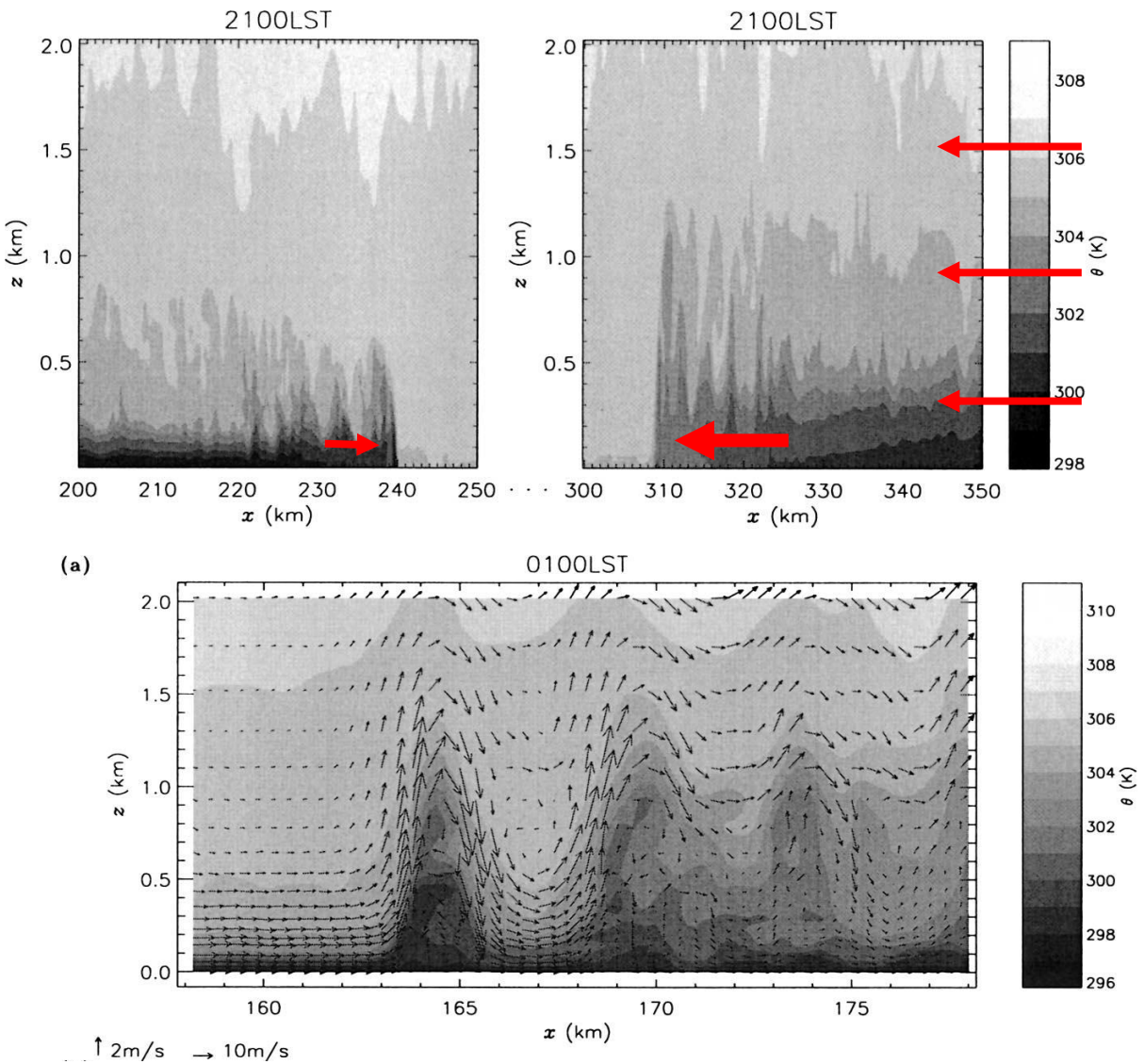
Atmospheric waves could be excited through collision of density currents and initiate convection

Woodhams et al. (2019)

Morning glory - Australia



Goler and Reeder (2004)



Collision of sea breezes of different depths excites waves

Storm case

Storm case

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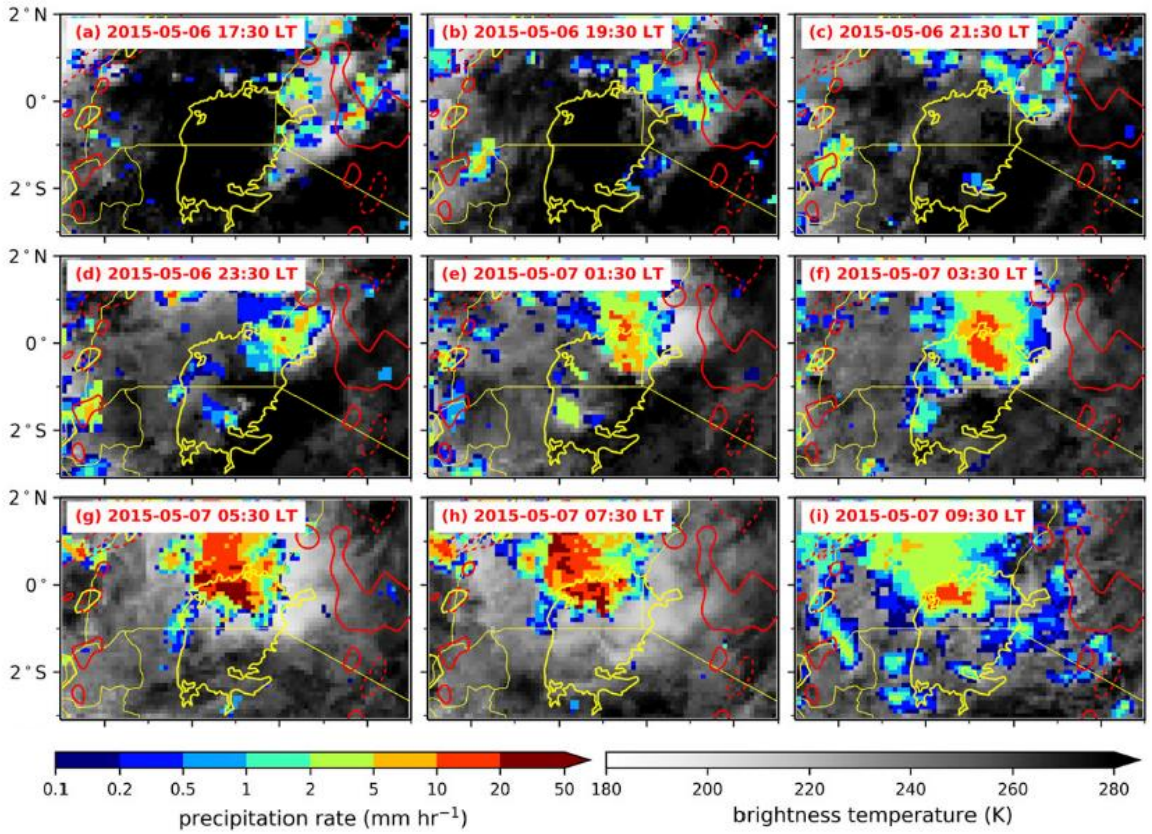
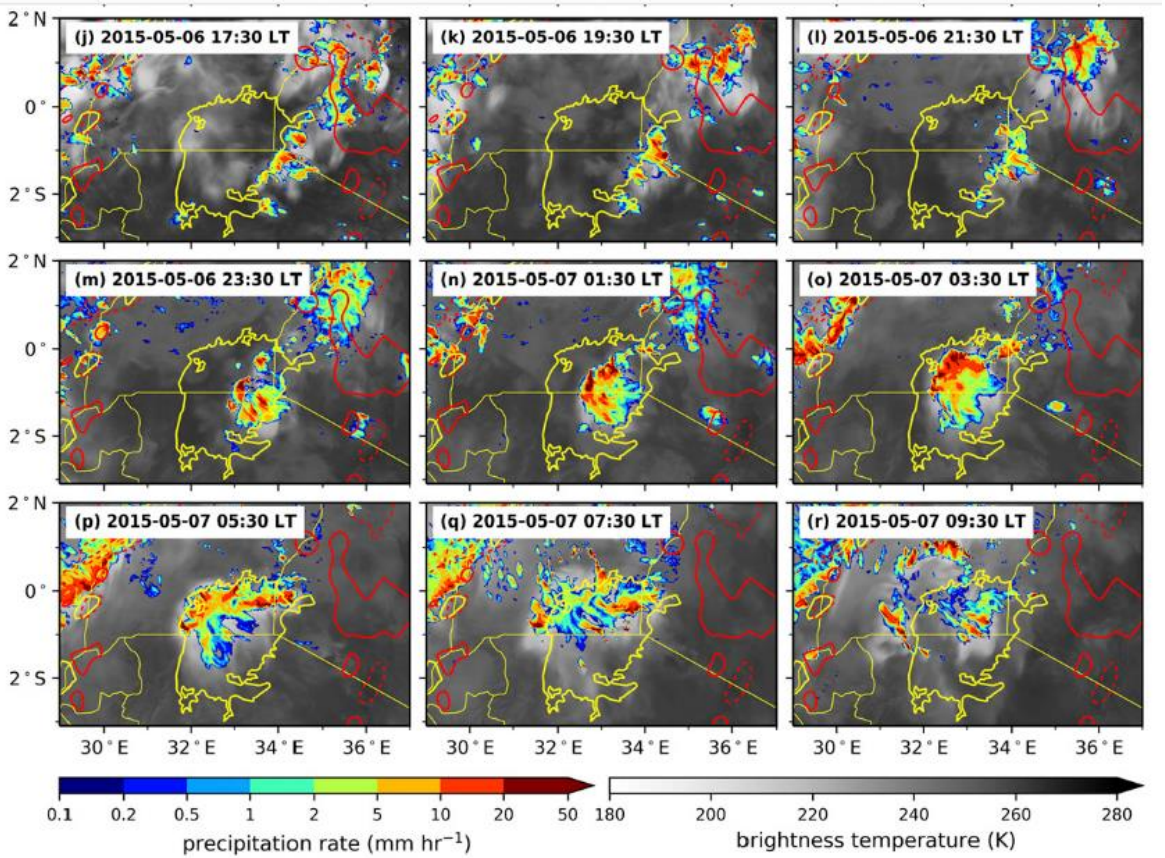
Observations



Model simulation



Woodhams et al. (2019)

Storm case

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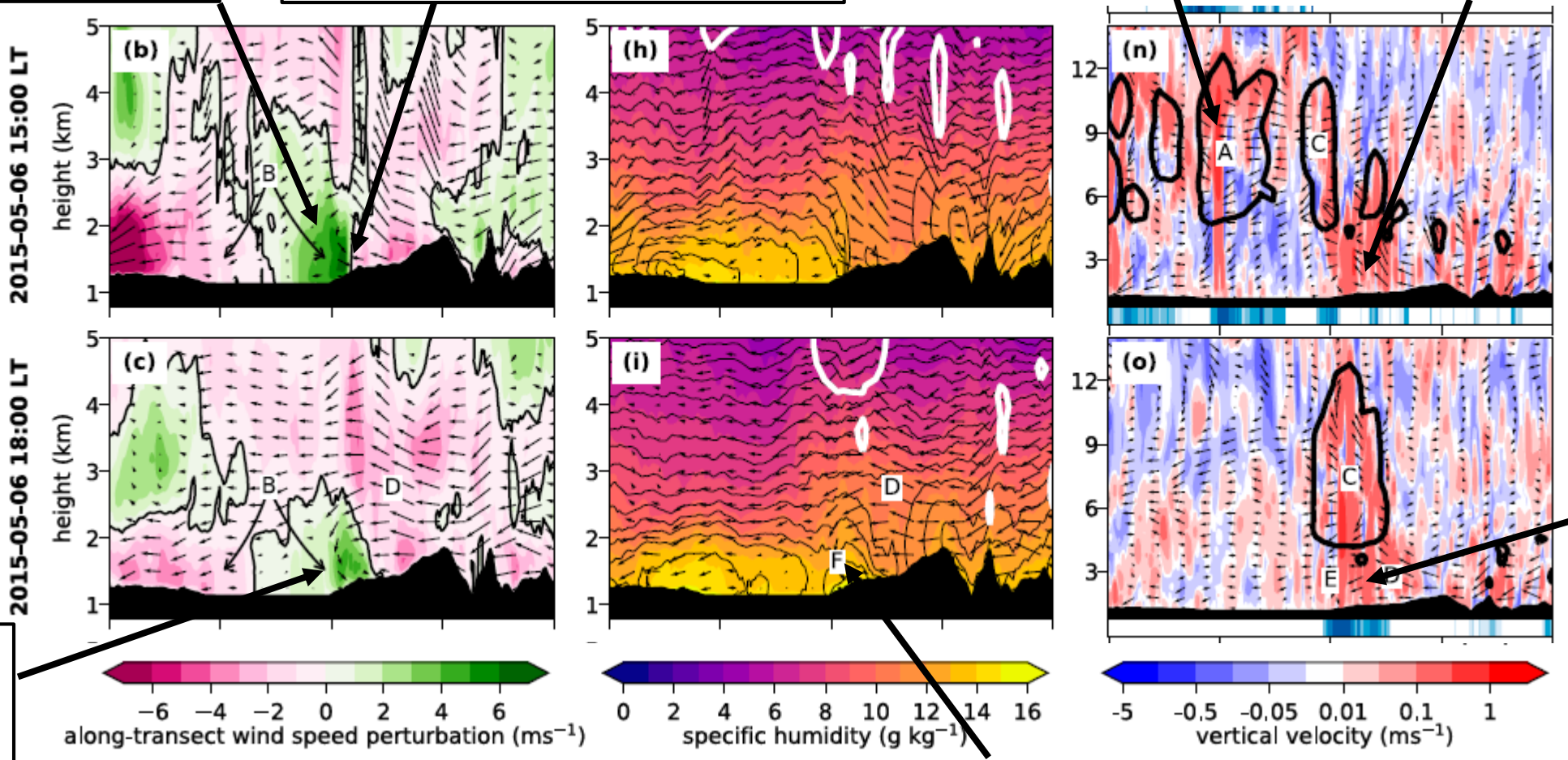
Strong lake breeze in the afternoon

Strong prevailing south easterlies converge with lake breeze

Storm from previous day

Convergence zone along coast



Onshore flow weakens in the evening

Storm develops with heavy rainfall

Cold pool develops

Woodhams et al. (2019)

Storm case

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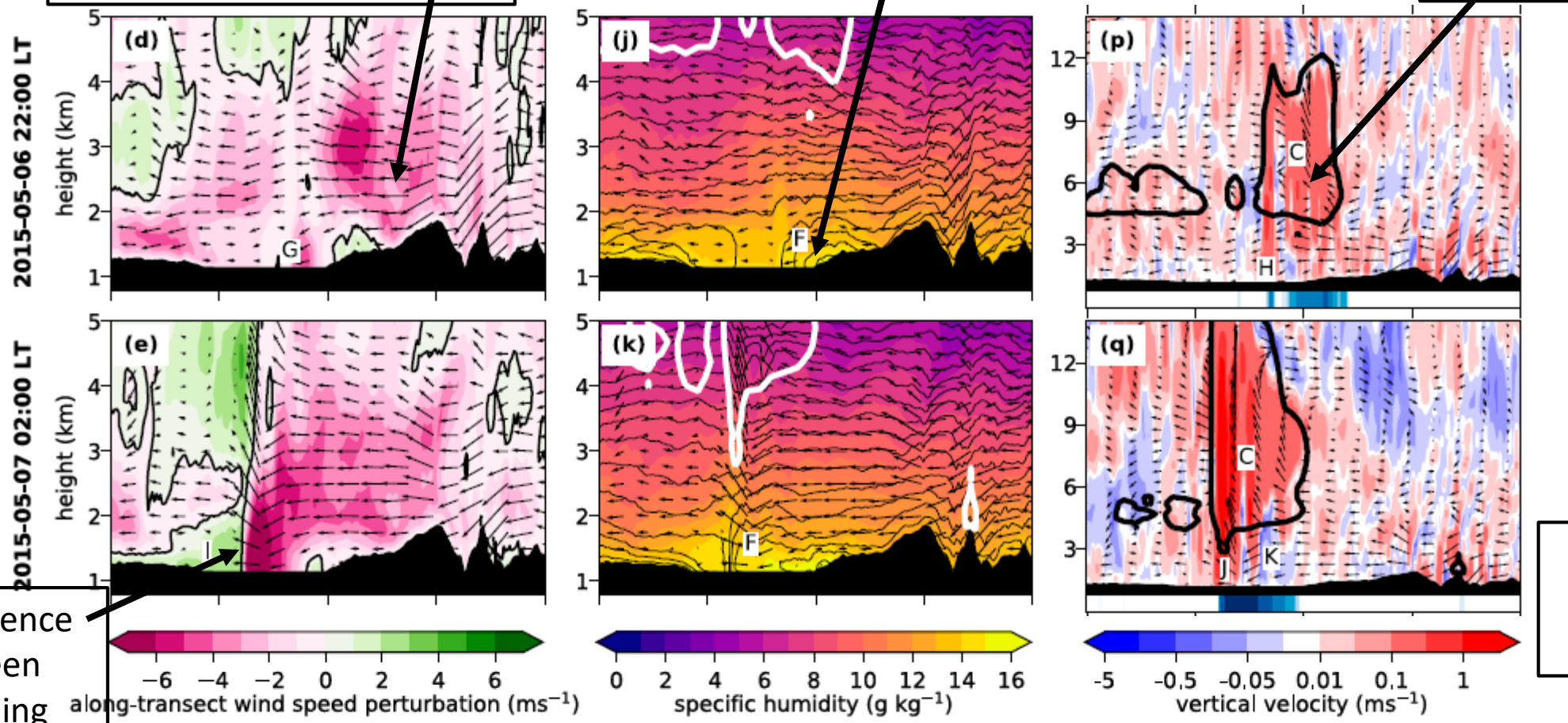
Prevailing southeasterlies accelerate

Cold pool

Storm propagates over the lake

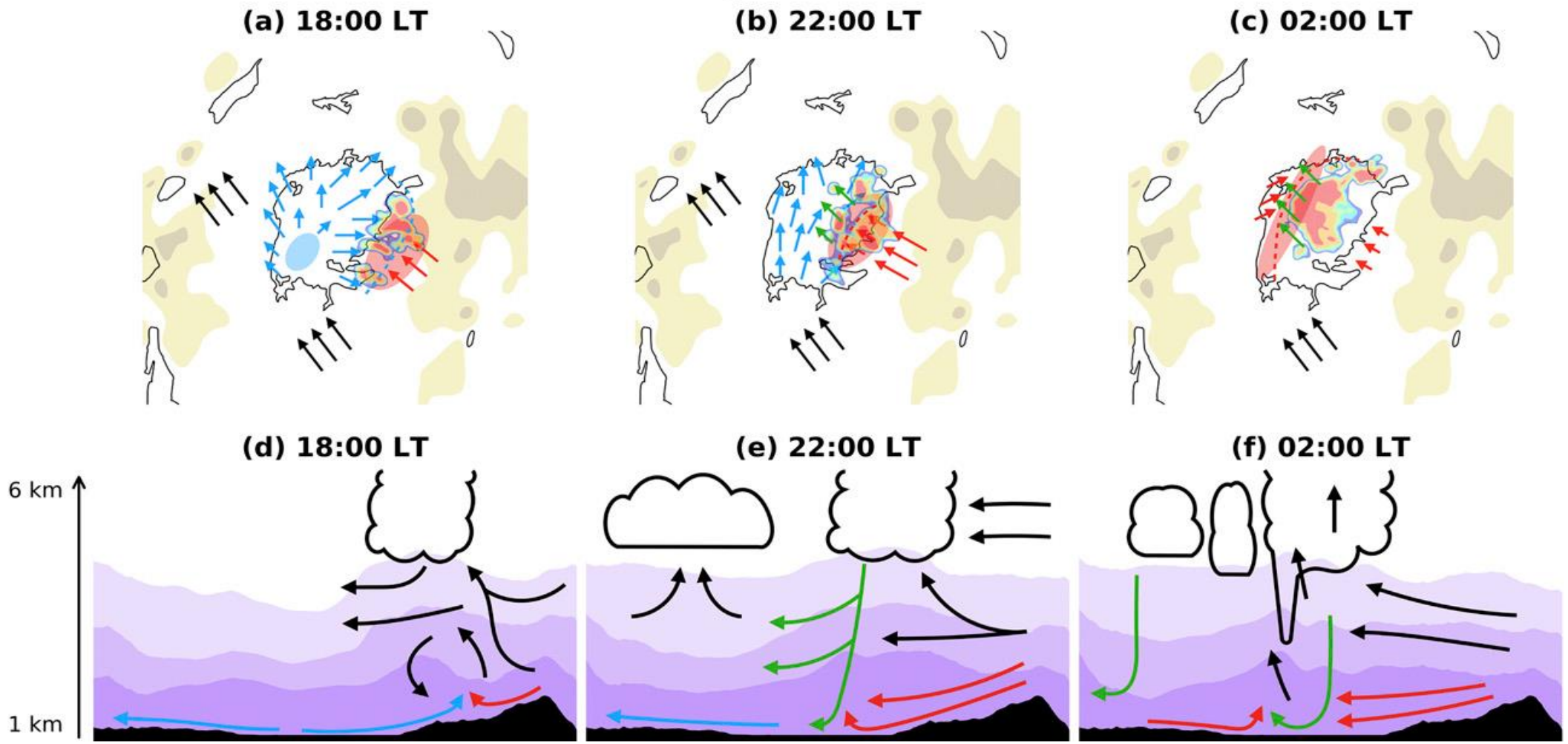


Convergence between prevailing southeasteries and land breeze

Convergence intensifies storm

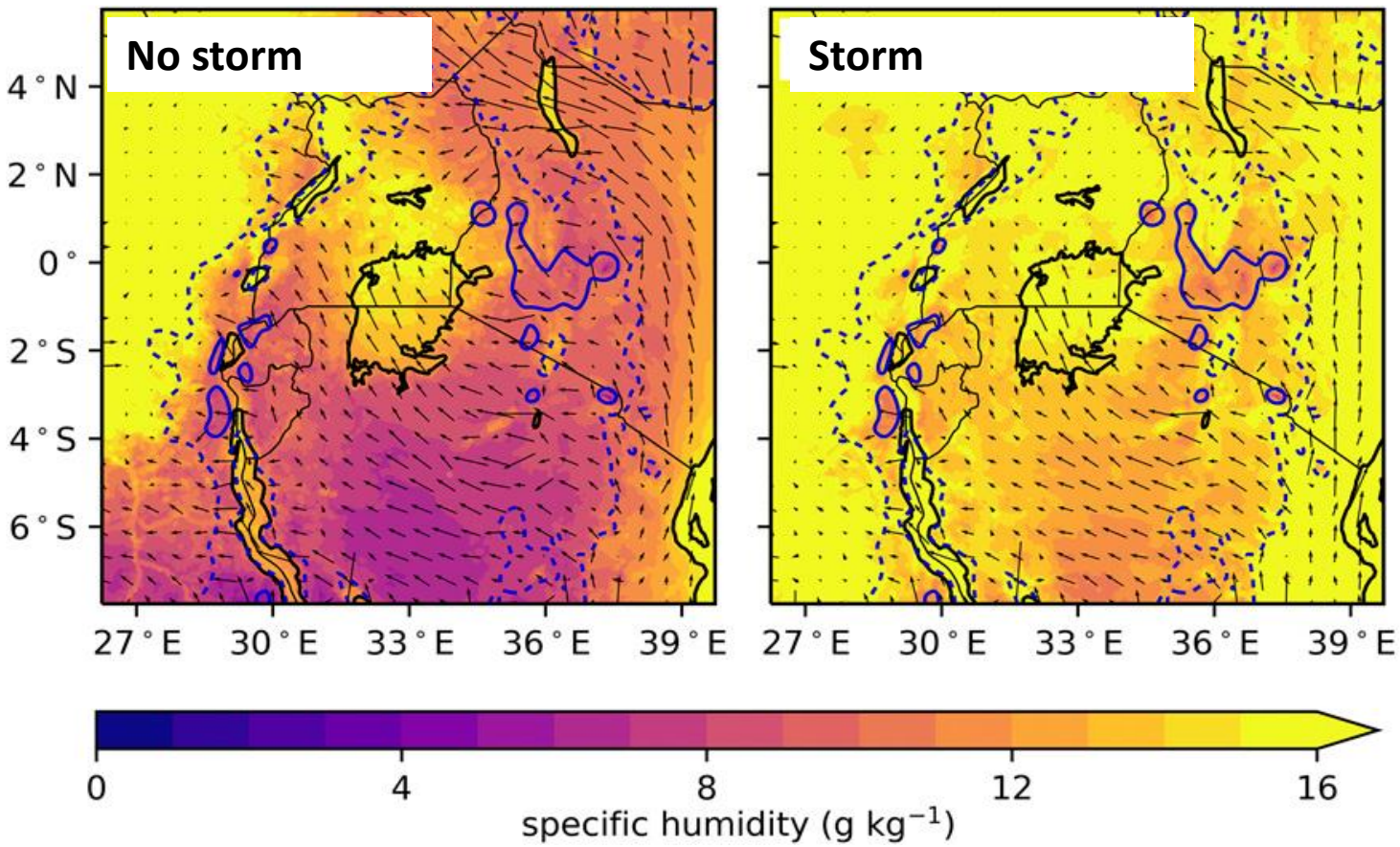
Woodhams et al. (2019)

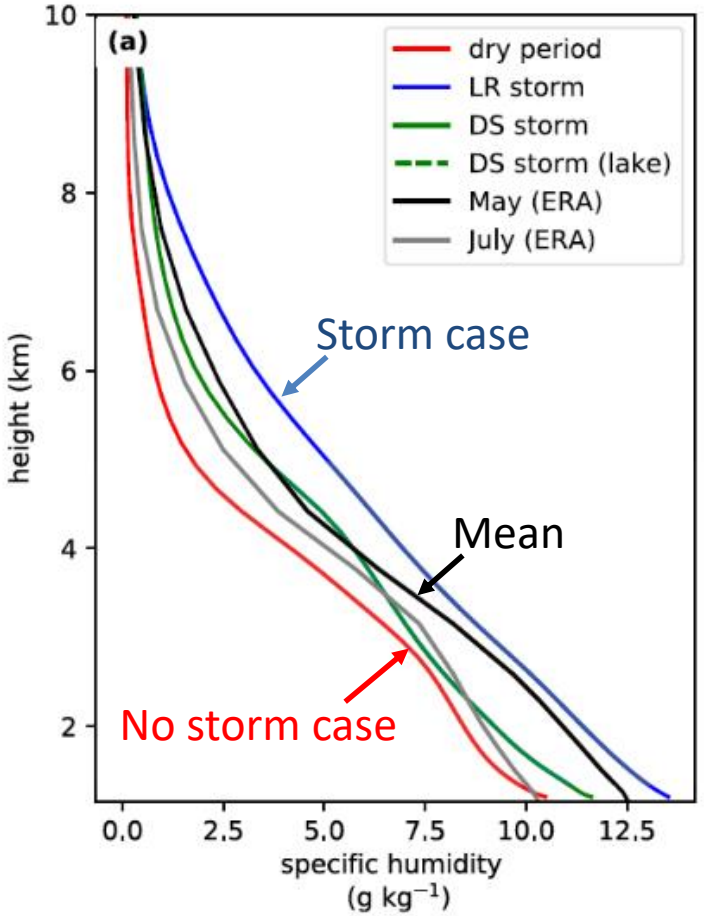
Storm case



Woodhams et al. (2019)

Large-scale controls on storm formation





- Lake-land breeze convergence occurs regularly
- Large-scale moisture is a key control on storm formation

Woodhams et al. (2019)

Lake Victoria

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- Controls on storm formation:
  - (Near?) persistent lake-land breeze circulation
  - Strength and location of lake-land breeze convergence
  - Prevailing wind strength and direction
  - Downslope mountain winds
  - Large-scale moisture availability – varies seasonally and sub-seasonally
  - Local moisture availability through evaporation
  - Moisture bulge and possibly waves
  - Lake-land surface temperature difference
  - Storm activity on the previous day – cold pools, moisture

- For accurate forecasts we likely need to simulate all above correctly
- Study based on three case studies in a model
- Idealised modelling needed to study land breeze collision + bulge
- Lack of detailed in-situ observations to evaluate models

Research flights

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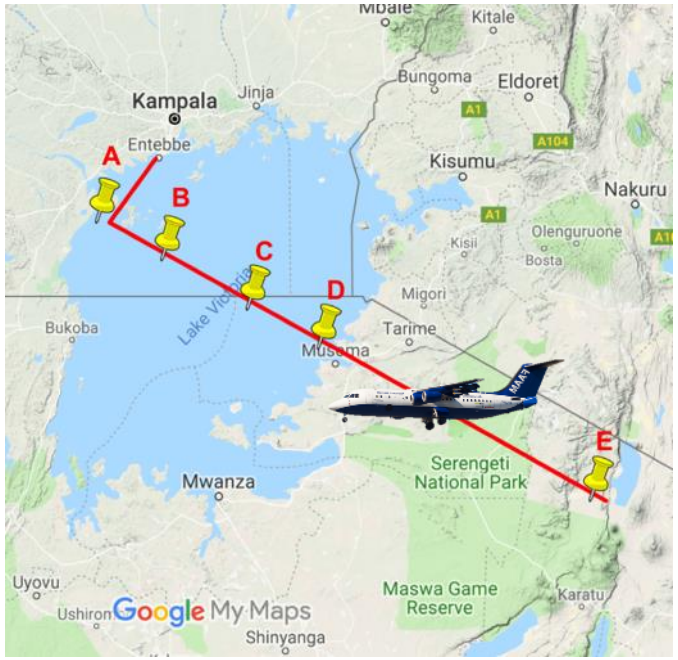
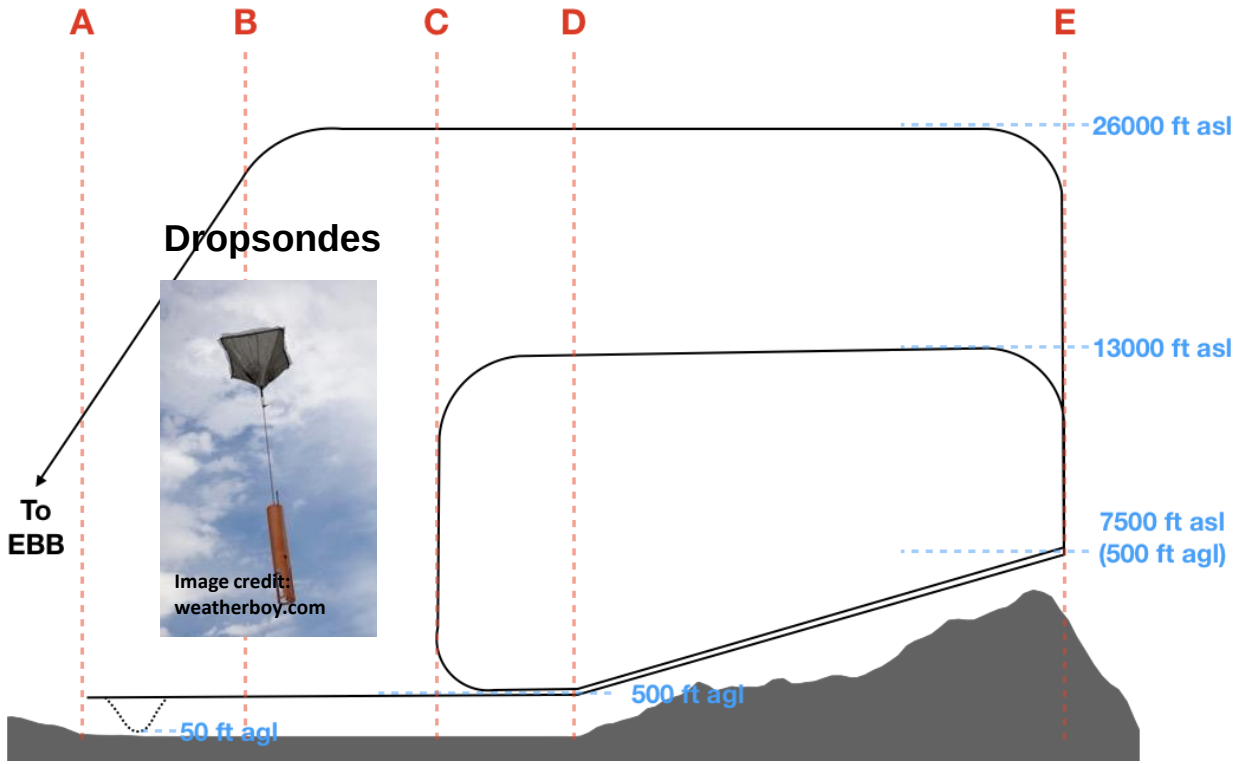
3 research flights through HyVic pilot field campaign, part of HIGHWAY and Africa SWIFT project

Research flights





Sondes to sample full profile

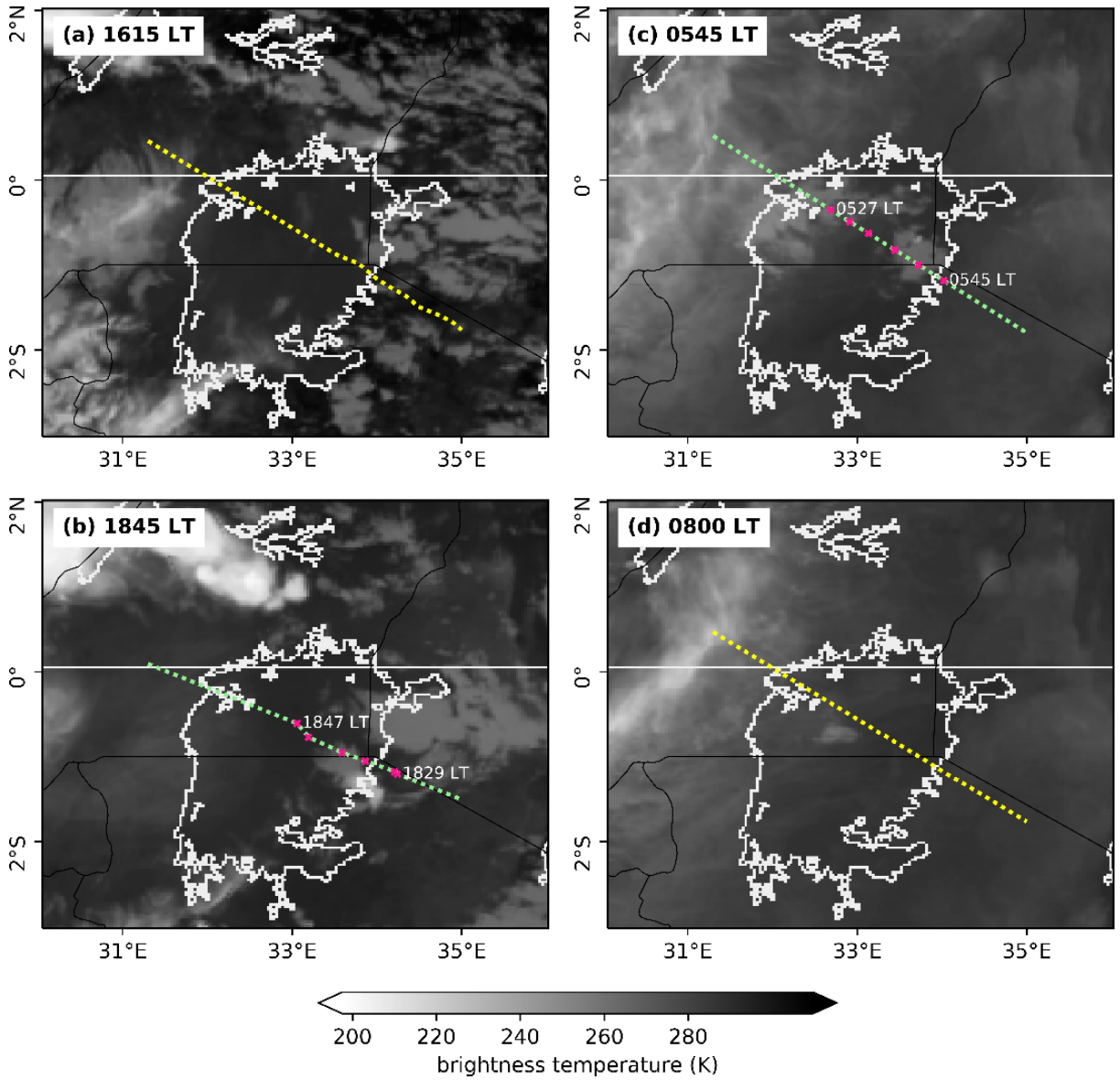
To sample return flow

To sample low-level convergence and contrasts between lake and land

- **26th January 2019 Evening flight:** sample lake breeze
- **27th January 2019 Morning flight:** sample land breeze and lake BL

Woodhams et al. 2021

Research flights



- January = dry season
- Storms often occur in dry season
- Clear conditions = lucky!
- Ideal to capture baseline lake-land breeze circulation

Woodhams et al. 2021

Research flights

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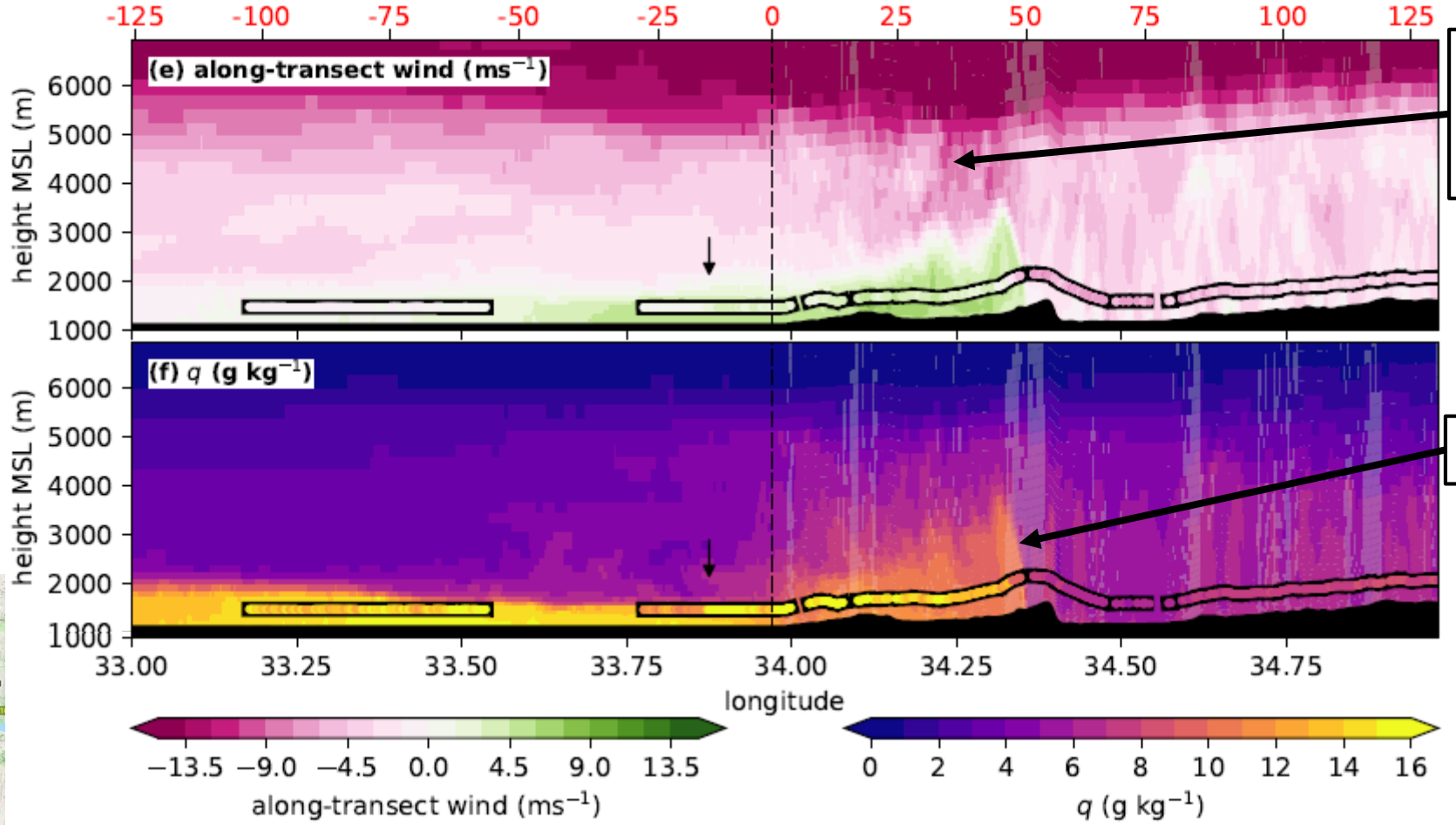
Evening flight

300m model data + low-level aircraft observations



Return flow aloft within prevailing southeasterlies

Lake breeze front

Woodhams et al. 2021

Research flights

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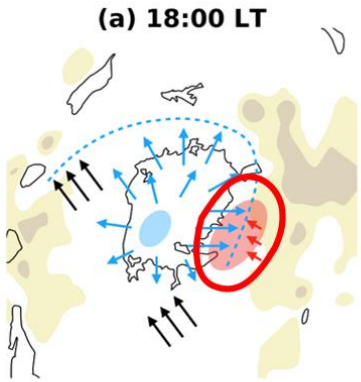
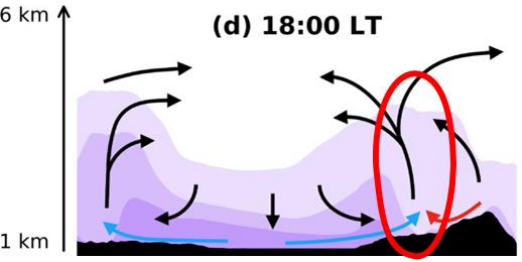
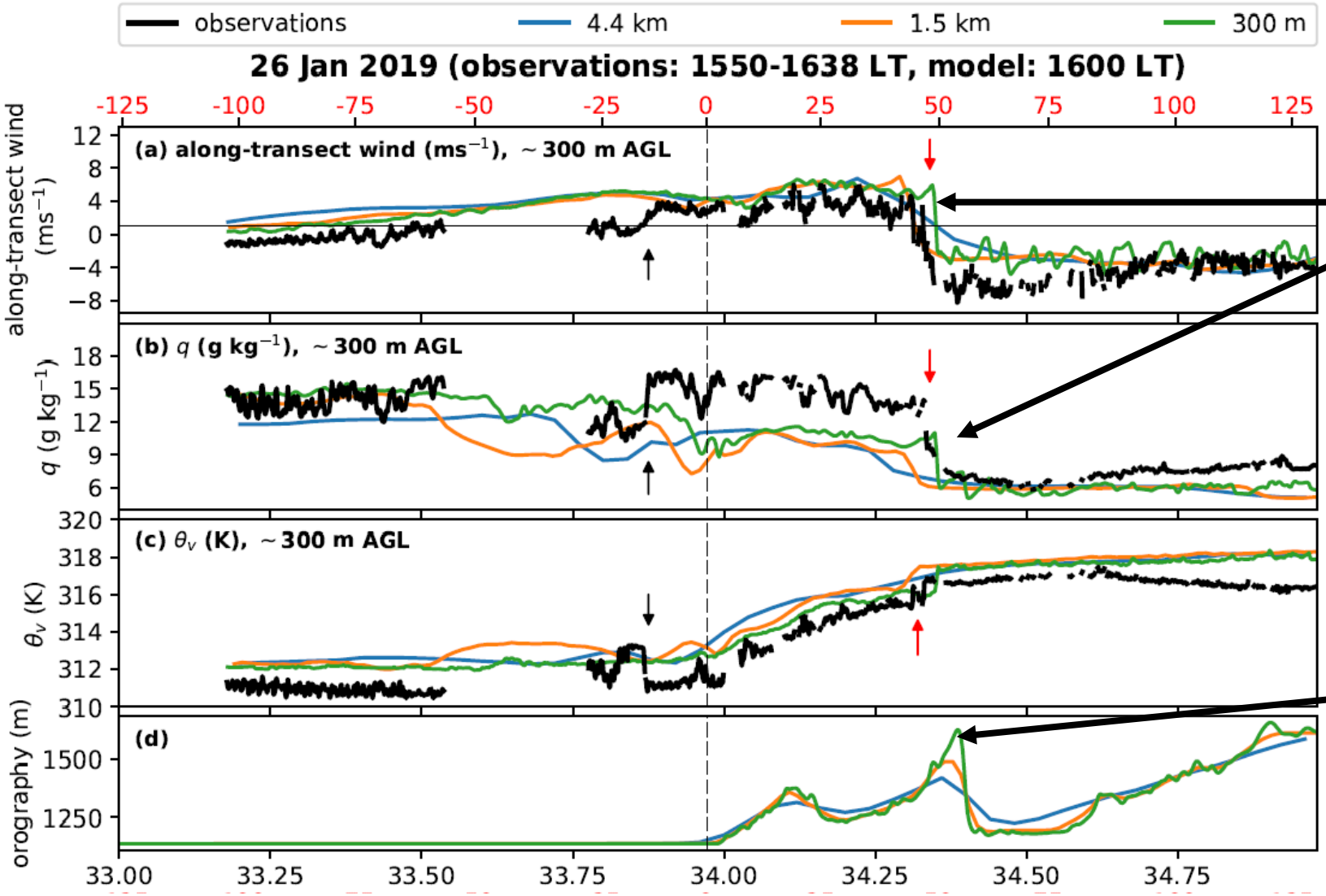
Evening flight

model data + low-level aircraft observations





Woodhams et al. (2019)



Lake breeze front much sharper in 300m model

300m model better resolves steep slopes

Woodhams et al. 2021

Research flights

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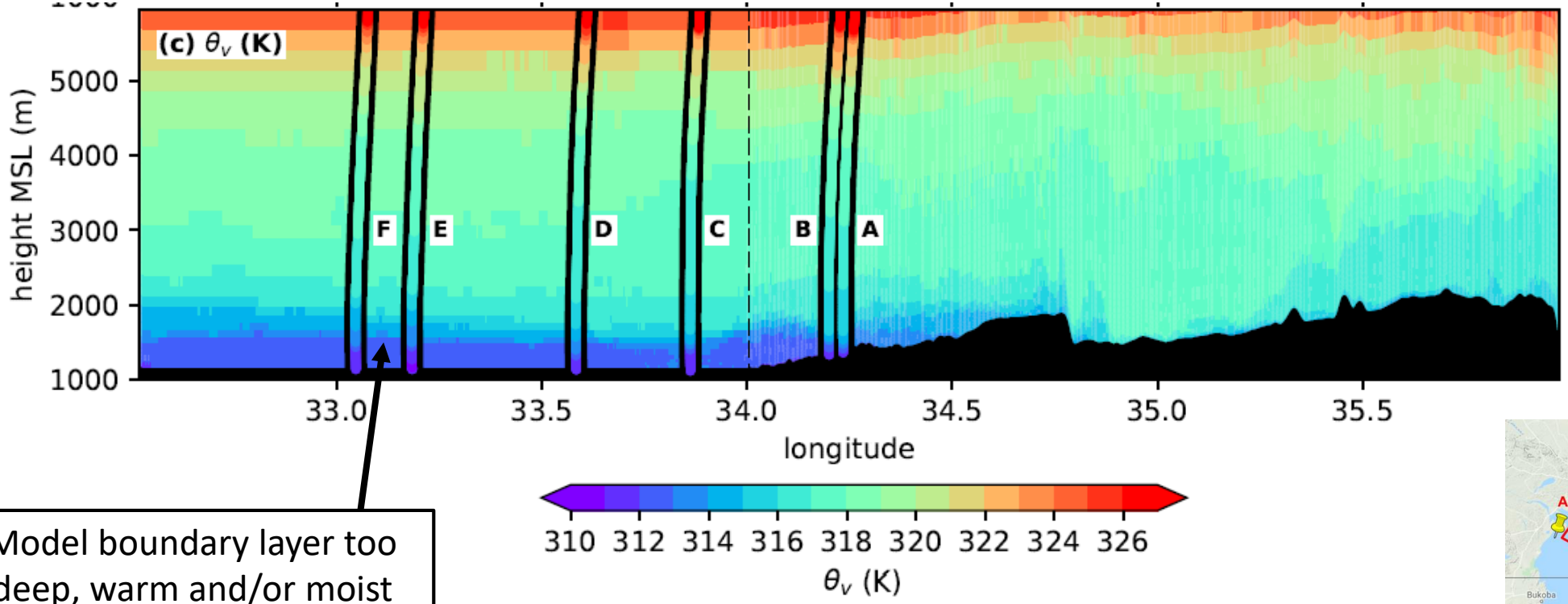
Evening flight

300m model data + dropsonde observations



Model boundary layer too deep, warm and/or moist

Woodhams et al. 2021

Research flights

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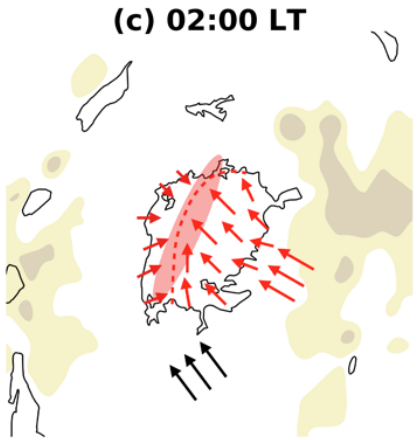
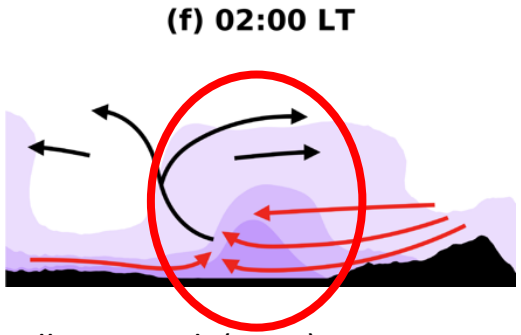
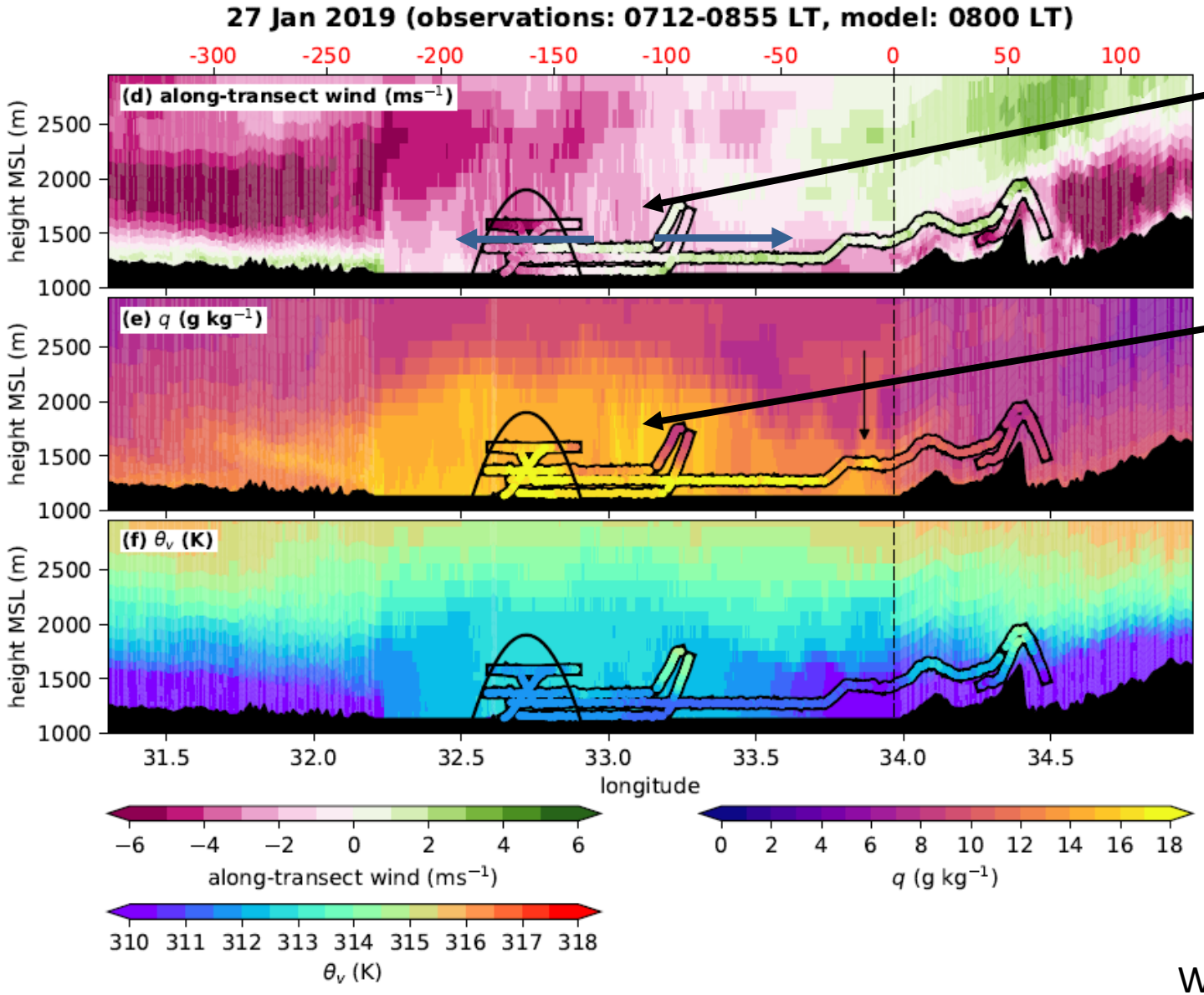
Morning flight

300m model data + low-level aircraft observations





Woodhams et al. (2019)



Low-level divergence over the lake

Bulge of elevated moisture

Bulge moved westward 10-20km in 2-3 hours

Woodhams et al. 2021

Research flights

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- First in-situ observations of the Lake Victoria lake-land breeze circulation
- First observational evidence of elevated moisture bulge over lake

- Can the model represent the key controls on storm formation?
  - Prevailing wind strength and direction ✓
  - Large-scale moisture variability ✓
  - Downslope mountain winds ✓
  - (Near?) persistent lake-land breeze circulation ✓
  - Strength and location of lake-land breeze convergence **?**
  - Moisture bulge ?
  - Local moisture availability through evaporation X
  - Lake temperature X
  - Storm activity on the previous day – cold pools, moisture X

- Storm days are more complicated to model, observe and understand

Research flights

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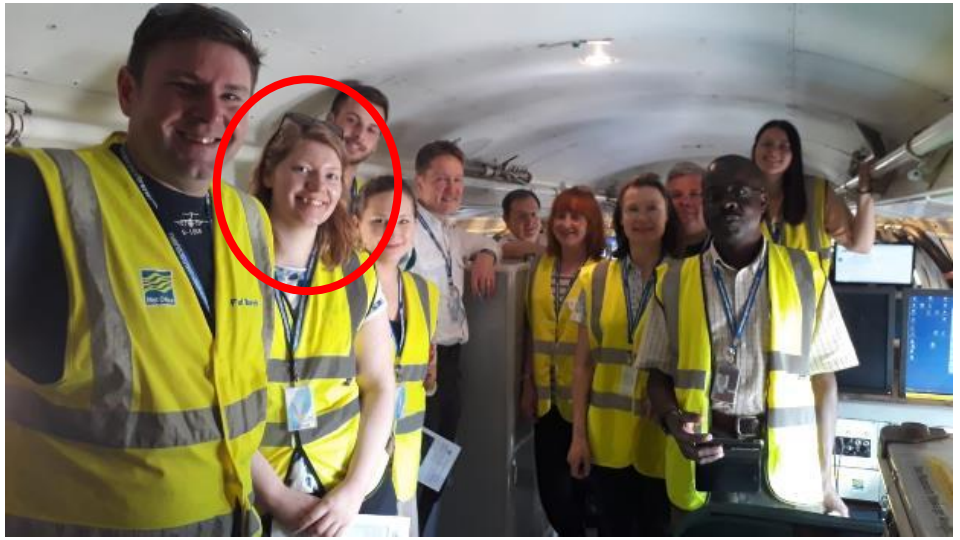
- HyVic ***Pilot*** Field Campaign
  - Extremely successful
  - Extensive modelling prior to the field campaign allowed us to target the correct time of day and vertical levels to sample, with only three flights
  - Luck with the dry conditions
  - Shown that a field campaign over Lake Victoria is feasible
  - Shown how useful in-situ observations are for model evaluation

- Much larger field campaign in the future



Summary

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- Forecast skill in the tropics remains limited, especially over Africa
- Regular severe weather in East Africa
- Forecast communication methods exist
- More detailed, in-situ observations and process studies needed to:
  - better understand the controls on storm formation
  - allow more statistical studies
  - diagnose model biases, leading to improved forecasts
  - develop better parameterisations for global models
  - understand ways to post-process forecasts to in order to improve skill
- Better routine observation network

References

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Questions?

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